# Does Noise Stationarity Matters on Spatial Formation of Real Estate Values? A GWR Analysis for Barcelona's Residential Market[1]

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## Abstract

The noise has become a major environmental cost that contemporary societies pay for living in densely urbanized areas. The impact of this externality on quality of life is reflected in a decrease of household's welfare level, and subsequently, in a reduction in property values. Using hedonic pricing (HP) a considerable number of studies have assessed the impact of noise on property markets, but few of them have considered the existence of submarkets. Theoretically it would be expectable that marginal value of 1 dB varies according to neighbourhood's noise exposure, features of dwellings (e.g.: insulation level) and the annoyance experienced by its residents. In this paper, using GWR, which resolves spatial dependencies (i.e. spatial autocorrelation) at the same time that considers "soft borders" among submarkets, it is studied the impact of noise on the value of a sample of multifamily dwellings at Barcelona. Analysis suggests that the level of noise does matters, although the NDSI found (0.08%) is in the bottom decile of HP studies reviewed by Navrud (2002). What is relevant is that the NDSI is not stationary throughout the city, suggesting that each dB have different impacts that seems to depend not only on the intensity to which dwellings are exposed, but also on the nature of noise source. Moreover, unlike other studies, in Barcelona WTP for a dB of "peace and quietness", coming from a contingent valuation study, is higher than the implicit price of noise arising from the research reported here.

## Keywords

Hedonic pricing, contingent valuation, noise valuation, real estate market, Barcelona.

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# Introduction

Compared to other externalities the study of noise impact on quality of life is quite recent. The Report "Fighting Noise in the 1990's" (OECD, 1991) was the first document that remarked the pollutant facet of noise, after which it started the assembly of respective EC policy (see Garcia and Garrido, 2003); in this context the assessment of noise's marginal value has become essential in the cost-benefit framework (Vainio, *et al.*, 2001). However, this task is twice complex: firstly, the value as a social construction, derives from the individual perceptions (Marmolejo & Romano, 2009), and secondly silence does not have explicit prices, since it has features of public good (i.e. not exclusion nor rivalry on its consumption).

Annoyance derived from external noise (produced by vehicles, pedestrians, pubs, etc.) in a given residential environment is a perception that depends on: 1) the nature of the source (frequency, intensity, intermittency, duration, etc.), 2) the exposure level (propagation, isolation, reverberation), and especially 3) the sensitivity level of its residents. Such a sensitivity is related to people's demographic aspects such as age (which correlates with deafness level), but mainly to cultural and social environment. The socio-cultural conditions, for example, influence the type of sounds that are interpreted as noise (Daumal, 2001), as well as the use of the domestic time (read, talk, listening music, study, etc.) which determines the disturbance produced by external noise (Kryter *et al*., 1972). Therefore, although the level of exposure is maintained along the day, people feel more disturbed during resting periods especially at night if sleep disruptions are present (conciliation, intermittency, deep consciousness, sleep duration), and at weekends as well (Bristow & Wardman, 2006). In this sense, Kuno *et al*. (1993) have suggested that lifestyle and appraisal of sound sources (i.e. assessment and/or dependence), such as cars, will also influence the judgment of which sounds are interpreted as noise.

Generally, noise nuisance provokes a reduction on people's welfare level since it not only disturbs their daily life (Cohen, 1980; Evans & Lepore, 1993; Evans, 1998; Hygge *et al.,* 1998 and Haines *et al*., 1998), but also has implications on their physical and mental health (Berglund *et al*., 1995). In economic terms, such a welfare loss would be equivalent to a damage function (Navrud, 2002). According to economic theory, such a damage can be expressed in monetary units if it is related to the trade off, on the consumption of other goods, necessary to enjoy a quieter environment (Carlson & Mitchell, 1988; Freemann, 1992). From the empiric perspective, most studies have used hedonic pricing functions (HP) to infer the marginal value of silence. However, few of them have considered the existence of submarkets, and when they do have, such submarkets have been clearly-spatially-delimited, which might bias the coefficient's function by mixing different submarkets (e.g. in a given assumed spatial submarket may be small and large dwellings belonging to different submarkets); as well, such a clear delimitation does not allow to considered the interdependences (i.e. externalities) between submarkets.

In this paper we use Geographically Weighted Regression (GWR) to assess noise's impacts on residential market values. This method allows: (i) to prove the existence of submarkets through determination of *local* coefficients statistically different across the city, (ii) to consider "soft borders" between different local calibrations which allows to considerer interdependences between them in a softened way, and (iii) resolved in this way, space dependencies (i.e. autocorrelation).

The rest of the paper is organised as follows: 1) Firstly, a brief literature revision is made in order to describe the HP methodology and highlight its meaning and limitations, 2) secondly a review of the results of other noise-HP studies is offered, 3) Thirdly, it is described the data and models and, 4) finally, results are discussed. The paper ends summarising the research and remarking the main findings.

# 1. Noise assessment from the perspective of revealed preferences.

The HP method, belonging to the revealed preferences family, assumes that in the value of a given property is implicit the marginal value of its attributes (Bøjrner, 2003). In practice real estate's values are used to econometrically infer the marginal value of silence, after controlling for the rest of location and structural attributes (Lancaster, 1966). In a urban system in equilibrium, the damage function produced by noise in a given point, should be compensated by a reduction on the rent paid for the land, equalising, in this way, the individuals utility level inside the system, consequently nullifying the mircromotives that may incite them to relocate, since such relocation would not increase their welfare (Bateman, *et al*., 2001). In this way in a function as (1), where the dependent variable *P* is the price, and the covariates *k* are the *n* structural and location attributes, including the noise, it is expected that the sign of the coefficient $k_r$ of this latter would be negative.

$$P_i = f(k_1, k_2, k_r .., k_n) \qquad (1)$$

As observed the main strength of this method resides on the fact that marginal price of attributes are directly derived from the observed behaviour of individuals on the real estate market. Nevertheless it has some limitations:

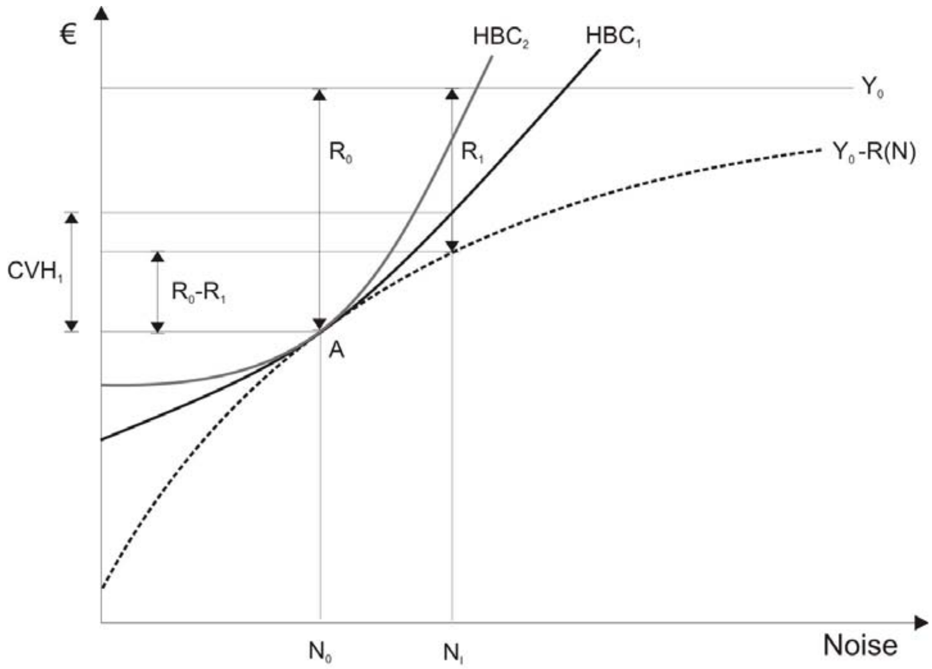
> *In relation to the damage perception*: It is assumed that when individuals (i.e. households), buy or lease a dwelling, are fully aware not only of the noise level that they will be exposed to, but manly, know the reduction of their welfare that will be consequently produced. This assumption is by far implausible because informational asymmetries in real estate markets are enormous, since the estates are not perfectly interchangeable among them, and because the perception is complex as it *is difficult to assess the impact that it will produce an event that has not yet been experienced*. These situations can lead to instability on the implicit WTP (Becker & Lave, 2003). And the marginal noise value may be undervalued due to the influence on the market of individuals less sensitive to it.

*In relation to the specificities of the real estate market*: In theory, if individuals find unmet their expectations concerning a given good they should immediately sell it and substitute it by other, readjusting in this way its price (Feitelson, *et al*., 1996). Nonetheless, it is not the case in the real estate market due the significant transaction costs (e.g.: furniture moving, taxes, commissions, legal services, etc.). The main assumption of the method is that individuals, in order to maximize their welfare, should choose those goods whose attributes have a marginal value which coincides with its marginal willingness to pay (WTP) for each one (Rosen, 1974). This assumption is frequently challenged by the way in how decisions are made in real estate markets, since individuals does not have enough time, information and alternatives to chose exactly the estate which attributes have the same implicit price that the individuals WTP for them.

*Related to econometric analysis*, there are also problems related to: (i) data sources (e.g. analyses often use databases designed for different purposes), (ii) the nonexistence of socio-demographic data of buyers (especially relevant in explaining the demand curve of WTP individuals in the HP second phase), and (iii) problems related to econometric specification of models and/or omission of relevant variables, as has been demonstrated by Bateman, *et al*. (2001) in their Glasgow study. This latter problem is especially important in the noise assessment since the noisier areas are often also the best served, so it is necessary to control this latter zone attributes.

In the context of the above mentioned limitations, the arising question is: whether the implicit marginal price of noise matches the damage function produced by it on individual's welfare. Following to Brookshire *et al.* (1982), Feitelson *et al*. (1996: 5-6) try to answer this question as follows: in Fig. 1 the horizontal axis represents noise levels, meanwhile the vertical axis is a composite good (excluding housing) with a price of unity, and thus it also represents Euros. $Y_0$ is the households average income level, and $Y_0$-$R(N)$ is the income available for purchasing composite commodity, after $R(N)$ has been paid for housing. As depicted the bigger the noise level, the lower the rent paid for housing. $HBC_1$ is the bid curve of household 1 for residence, by means of which, noise and composite good are traded off. Location A is the original situation, here household 1 maximizes its utility since marginal noise value and marginal WTP coincide (Rosen, 1974). Nonetheless if noise level increases from $N_0$ to $N_1$ the compensating variation for household 1 is $CVH_1$ (the amount necessary to accept the new noise level but maintain the original utility). Nonetheless house's rents decline only $R_0$-$R_1$ since market rents does not respond to a specific household utility function but average. In such a case, the decrease in house prices does not fulfill the compensating variation and produces a decrease on household's welfare (Palmquist, 1992), in this way, hedonic marginal function underestimates the noise impact on household's 1 welfare. Fig. 1 also depicts the situation for household 2, which has a steeper bid curve (e.g.: more annoyed by noise), thus widening the gap between welfare loss and compensated rent reduction. Of course the opposite situation would occur in the case that the hedonic or implicit marginal function would have a smoother curve compared to marginal households WTP, as stated by Bøjner (2003: 91): "the differences between the HP for changes in noise levels and individual WPT depend in the shape of both curves".

**Figure 1. Marginal WTP versus implicit price schedule.**




Source: adapted from Feitelson *et al.* (1996)

Therefore it cannot conclusively be stated that the noise marginal is a perfect measure of the change in the individual's welfare level, although both measures are correlated (Walters, 1975; Brookshire, *et al.*, 1982; Feitelson *et al.*, 1996; Bøjrner *et al.*, 2003; Onjar, 2004; Nelson, 2008). An alternative approach of monetary measurement of the welfare level is given by the contingent valuation (CV). This method, which belongs to the family of declared preferences, tries to know directly the equivalent or compensatory variation necessary to access or forgive a given environmental quality improvement (Soguel, 1996). Using sociological surveys, CV directly extracts people's willingness to accept (WTP) or to be compensated (WTC) for enjoying or forgiving a given hypothetical improvement (Mitchell & Carson, 1989)[3]. Despite the potential of CV some scholars and practitioners are sceptical about its efficiency; since they hesitate whether respondents declare behave in the same way as they would do in a real situation. Probably for this reason, in the noise assessment field, CV has been less applied compared with the method of hedonic pricing. So while CV focus directly in measuring the changes in the welfare level of subjects produced by changes in environmental quality, HP

[3] There are three main advantages of this methodology: (i) allows direct isolate the marginal value of the change in environmental quality, (ii) to assess the impact on the welfare level of non-use values (e.g: opportunity, existence, and permanence), and mainly (iii) it's quite versatile since it allows to evaluate potential changes or alternatives (Freeman, 1993).

discusses the extent on which of these changes are reflected on property prices (Bateman *et al*., 2001). The election of the method depends up the objective to which the study has been designed for.

## 2. The noise impact on dwelling prices.

In literature the most widely used indicator to measure the noise impact on property's value is the Noise Depreciation Sensitivity Index (NDSI). The NDSI, originally developed by Walters (1975), indicates the variation of price in percent terms for each unit of noise exposure. Such an exposure can be measured in different indexes, some of them are composites, such as NEF, ANEF, or NNI[4], which combine the tone, intensity (dB), frequency of noise-impacts in a defined interval of time (e.g.: take offs and/or landings in airports), duration and time at which occur (day or night), while other indices are simpler, such as Leq, Ldn or L10.

Recently Navrud (2002) has summarized the results of 65 noise assessment studies (of which 58 per cent are related to vehicular traffic), from this set of the most widely used index, in 62 percent of cases, is the NDSI. The analysis of these results for the case of vehicular noise reported in Fig. 2 suggests that NDSI has an average of 0.64% (i.e. for each dB of noise increment the dwellings price is reduced in 0.64%), with an interquartile range (50% of cases) going from 0.26% up to 0.89%, in general 90 per cent of these studies have reported a NDSI inferior than 1.23%.

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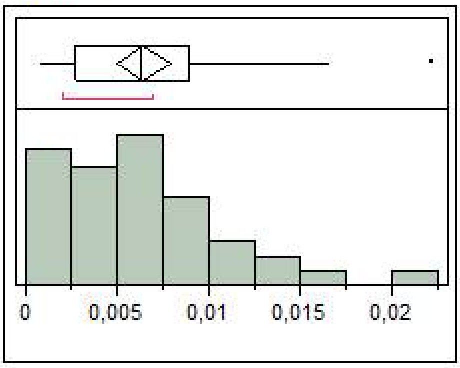
[4] The NEF (noise exposure forecast), developed by the US Federal Agency of Aviation, is a composite index constructed from EPdB(effective perceived noise level) which in turn finds the tone and duration of the event, and number of events during the day and night. The ANEF is the adapted version of the NEF for Australia. The NNI developed by the British Wilson Committee, unlike previous indexes, tries to measure the annoyance of aircraft noise from the perspective of the subject that perceives it, therefore, is based on a survey. The Leq (equivalent noise level) and Ldn (day night average sound level) are more simple, the first measures the sound pressure during half an hour, the second takes into account the average intensity of sound occurred in a period of 24 hours, penalizing that which occurs between 10 pm. and 7 am., although those time period can change, for example in the EU it is taken from 23 pm. to 7 am. Besides all, the L10 is the equivalent noise level which has exceeded 10% of the measured time.

**Figure 2. Traffic noise NDSI histogram based on studies reported by Navrud (2002).**




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 0,02220 |
| 99.5% | | 0,02220 |
| 97.5% | | 0,02206 |
| 90.0% | | 0,01239 |
| 75.0% | quartile | 0,00895 |
| 50.0% | median | 0,00635 |
| 25.0% | quartile | 0,00268 |
| 10.0% | | 0,00156 |
| 2.5% | | 0,00082 |
| 0.5% | | 0,00080 |
| 0.0% | minimum | 0,00080 |

**Moments**

| | |
|---|---|
| Mean | 0,00645 |
| Std Dev | 0,0044736 |
| Std Err Mean | 0,0007073 |
| upper 95% Mean | 0,0078807 |
| lower 95% Mean | 0,0050193 |
| N | 40 |

In Table 1 are summarized some NDSIs found in other researches. The significant divergence on the results from each study is not surprising, from a theoretical perspective, since each NDSI calibration is intrinsic to its specific real estate market, it means that each urban market is characterized by a particular implicit price for silence. In this sense, Schipper *et al.* (2001), based on an 11 HP-studies meta-analysis[5], found that the significant variables that allows to explain the divergence of NDSI are: time, location (country, and accessibility features of the neighbourhood) and specification of the original models.

In the same way that NDSI varies among cities there are no theoretical reasons to expect that within a single city it should remain constant or stationary. Furthermore, some studies like that from Becker and Lavee (2003) suggests that the impact of noise is not linear throughout the space. Based on the analysis of 3 Israelite cities, their findings suggest that noise has a deeper impact on suburban residential prices in areas which are adjacent to countryside. Namely per each dB Leq that noise increases dwelling prices are reduced by 2.2%, while in inner city areas this impact (NDSI) is significantly smaller and equivalent to 1.2%. This suggests that noise is more penalized in areas expected to be quite; this conclusion has also been highlighted by Baranzini & Ramirez (2005) for Geneva's rental market, and by Marmolejo & Romano (2009) in a CV study at Barcelona's airport surroundings. In the same path, Collins & Evans (1994) following the research initiated by Pennington (1990) in the area of Manchester's Airport, have highlighted the differential impact of environmental noise and air traffic depending on the dwelling typology; like Rich & Nielsen (2004) in their Copenhagen study they reported a NDSI of 0.47% for apartments and 0.54% for houses; likewise Baranzini & Ramirez (*Op. Cit*) also found structural differences between their public and private rental models. *These studies suggest that noise does not have a stationary impact along the urban space, since noise might be internalised in different ways among submarkets.* In this line Day (2003) has reported significant differences in the NDSI derived from residential submarkets in

[5] Several meta analysis (Bertrand, 1997; Bateman *et al*., 2001; Schipper *et al.,* 2001; Nelson, 2004) have shown, moreover, that one of the main weaknesses of HP method is the instability of results as a result of problems in a functional and the specification of the models, as well as the very source information.

Glasgow, which have been previously delimited throughout a hierarchical cluster analysis using, location, socioeconomic and dwelling's structural features data. In his study, noise impact was deeper in areas inhabited by "young urban professionals" (NDSI = 0.57%) in relation to areas of "white tenants" (NDSI = 0.23%) and "ethnic minority tenants" (NDSI = 0.46%). In Birmingham Bateman *et al.* (2004) and Day *et al.* (2007) have been detected in the same way that Day did (2003) 8 submarkets, of which in 5 traffic and rail noise is significantly negative, meanwhile airport noise is significantly negative only in two.

**Table 1. NDSI reported in a selection of HP studies (mainly road traffic noise).**

| City | Author(s) | Year | NDSI | Index | City | Author(s) | Year | NDSI | Index |
|---|---|---|---|---|---|---|---|---|---|
| ***USA*** | | | | | ***Australia*** | | | | |
| | | | | | Newcastle | McCalden y Jarvie | 1977 | 1,9% | *** |
| Tidewater | Allen | 1977 | 0,15% | L10 | | | | | |
| North Virginia | Allen | 1977 | 0,14% | L10 | ***United Kingdom*** | | | | |
| North Springfield | Anderson & Wise | 1977 | 0,18% | Leq | Manchester | Pennington | 1990 | 0,47% | NNI |
| Towson | Anderson & Wise | 1977 | 0,43% | Leq | Manchester | Collins & Evans | 1994 | 1,5% | NNI *- |
| NS+TS+BG+RS | Anderson & Wise | 1977 | 0,25% | Leq | | | | | |
| North Springfield | Bailey | 1977 | 0,38% | Leq | ***Israel*** | | | | |
| Washington | Nelson | 1978 | 0,88% | Ldn* | Urban areas | Becker y Lavee | 2003 | 1,20% | Leq |
| Washington | Nelson | 1978 | 0,60% | Ldn** | Suburban areas | Becker y Lavee | 2003 | 2,2% | Leq |
| Kingsgate | Palmquist | 1980 | 0,48% | Leq | | | | | |
| North King County | Palmquist | 1980 | 0,30% | Leq | ***switzerland*** | | | | |
| Spokane | Palmquist | 1980 | 0,08% | Leq | Geneve | Baranzini & Ramirez | 2005 | 0,70% | Leq |
| Baton Rouge | Hughes y Simans | 1992 | 8,8% | *+ | | | | | |
| | | | | | ***Chile*** | | | | |
| ***Canada*** | | | | | Santiago | Aguirre & Ramos | 2005 | 2,36% | Leq |
| Toronto | Hall, Breston y Taylor | 1978 | 1,05% | Leq | | | | | |
| Winnipeg | Levesue | 1994 | 1,30% | Leq | ***South Korea*** | | | | |
| | | | | | Seul | Kwang, Sung i Young-J. | 2007 | 1,3% | Leq |

NS+TS+BG+RS = North Springfield+Towson + Bogota + Rosedale
* For noise increments above than 50 dBA Ldn
** For noise increments above the 39 dbA Ldn threshold
*** Price reduction when it exceeds in 17/trucks/hour the threshold of 33 trucks/hour equivalent to 60 dbA L50
*- For detached houses when noise level rise from 27 NNI to 40 NNI
*+ For dwellings located both in the city core and in its periphery in noisy streets compared to quiet streets

Source: Own elaboration using data from ENVALUE (www.environment.nsw.gov.au/envalue) and reported studies.

## 2.1 Hedonic implicit price schedule versus willingness to pay.

Few studies have attempted to compare the results of the HP method with the results of contingent valuation (CV). In the particular case of noise one of pioneering researches which compare the results of both methodologies was carried out by Pommerehne (1988) in Basel. This author interviewed households whose houses had been used to estimate, using the HP, the marginal value of a sound reduction by a half (8 dB), finding a WTP (CV) of 75 CHF per month (99 2001-Euros/dB/household/year) and 79 CHF (104 2001-Euros /dB/household/year[6]) with the method of HP. Soguel (1996), interviewed 200 households on Neuchatel (Switzerland) finding a WTP of CHF 56-67 per month (60-71 2001-Euros/dB/household/year), after having controlled the strategic potential bias, if the noise was reduced by a half (8 dB), while in his study of HP (Soguel, 1994) had found a value of 60 CHF for the same sonic reduction (64 2001-Euros/dB/house/year). The apparent coincidence of the results produced by both methodologies vanishes in the studies of Vainio (1995, 2001), who got in Helsinki a WTP (CV) of 6 to 9 2001-Euros/dB/household/year, while using HP the result was 22 2001-Euros /dB/household/year. As far as we know that the latest published study that using the same sample has compared the results of both methods was that of Bøjrner (2003). Using CV results suggest that WTP to reduce one dB, from a starting point of 60 dB, is DKK 28.65 per household per year (3.86 2003-Euros/dB/household/year). While the hedonic function for an equivalent reduction is DKK 86.66 (11.63 2003-Euros/dB/house/year) using a discount rate of 2%. Therefore, these four studies suggest that hedonic pricing produce values slightly higher than CV. In fact this is the thesis sustained by Brookshire *et al.* (1982), who have empathized that the implicit price schedule is the upper frontier of noise valuation. In this sense Bøjrner (2003) argues that such a upward bias could arise from the fact that it is very difficult, given the absence of data or high correlation, to separate the impact of noise from the impact of other externalities associated to the noise's emitting sources (e.g.: vibration, smoke, odours, accident risk, visual impact, and so on). As a consequence HP silence schedule may be masking the absence of other negative externalities which have not been explicitly specified in the regression models.

## 3. - Case study, model and data.

The municipality of Barcelona (100 sq. km and 1.59 million people) leads the second Spanish metropolitan area (3.200 sq. km and 4.85 million people). Its compact and diverse urban model has been recently worldwide awarded. However, one of the major costs of compactness is the significant level of environmental noise in a city with an intense public life, a great mixture of land uses, combined with a relative lack of acoustic greenery and a touristic sector in vogue. The latest published acoustic map (1997) suggests that only 23.4% of sonometric points got "good" conditions, it means those with a Leq less than 65 dB during daytime and a Leq less than 55 dBA on night time. Most of the points (63.8%) have a "tolerable" label (65-75 dBA for the day and 55 -65 dBA for the night), the remaining 12.8% are categorised as "to improve" it means that they are above the limits considered as "tolerable". What is surprising is that this classification from the authors of this acoustic map is quite optimistic compared with others made by international agencies: for example, the OECD

[6] The monetary conversions are in Navrud (2002) and have considered the inflation of each country, from the moment of completion of the study until 2001 and the conversion to Euros as the exchange rate of January 2002.

estimates that from 55-60 dBA noise causes discomfort, between 60-65 dBA annoyance is considerable, and above 65 dBA it produce serious disturbances and diseases (Garcia & Garrido, 2003, pp. 98). *In other words 2 of 3 of the council's own measurements are above the level of sonic disruption; this is the price of living in a compact and diverse dense city.* On this scenario, this research it's looking for measure the extent to which this externality is reflected on residential values.

The model used in this paper is specified in (2). Despite the fact that in literature there is no consensus on what variables should be considered (Mason & Quigley, 1996), there is certain agreement on the inclusion of variables affiliated to 4 basic dimensions (Roca, 1988; Tincher, 1995; Garcia-Almirall & Fitch, 2008). In this way in (2) the price *P* of a property *i* depend on a set of variables affiliated to the following categories: *S* structural (e.g. dwelling´s size, build quality, etc.); *A* accessibility (e.g. proximity to public transport stations, distance to CBD, etc.). *N* neighbourhood (e.g. resident's income level, etc.); and E environmental externalities (e.g. noise level, views, etc.). Finally *ε* is a vector which represents the random error (i.e. all those attributes and circumstances that affect the transaction price that have not been considered in the modelling process).

$$Ln(P)_i = B_i + \sum_{s=1}^{n} B_{is} S_{is} + \sum_{a=1}^{n} B_{ia} A_{ia} + \sum_{n=1}^{n} B_{in} N_{in} + \sum_{e=1}^{n} E_{ie} E_{ie} + \varepsilon_i \quad (2)$$

The semi-log function (2) responds to three reasons: i) the transformation suggested by Cox & Box (1964) of the dependent variable suggest, since λ is close to zero[7], that the price is linked in this way to the set of covariates; ii) in the noise HP literature it is the most widely used functional specification because, among other things, it helps to normalize the price and residual distribution, and allows to compare results from different studies (Kennedy, 1994; Bateman *et al.*, 2001; Navrud, 2002; Bøjrner, 2003), and iii) the noise coefficient, since it is calculated as a semi-elasticity, allows to know directly the NDSI (Nelson, 1980; 2004; 2008).

The market value used comes from 3,196 appraisals of multifamily dwellings (flats) carried out during the year 2005[8]. In Spain, since there are not comprehensive public or private databases

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[7]This transformation has been calculated as follows:

$$Y^{(\lambda)} = \begin{cases} \dfrac{y^{\lambda} - 1}{\lambda \dot{y}^{\lambda - 1}} \; if \;\; \lambda \neq 0 \;\; or \;\; \dot{y}\ln(y) \;\; if \;\; \lambda = 0 \end{cases}$$

Where $\dot{y}$ is the geometric mean. Please note that if λ is 1 then the equation collapses to a linear function (i.e. there is no need to transform Y), while if it approaches to zero, the transformation of the dependent variable is the log. In our case through testing different values of λ to reduce sigma and analyzing the normality of residuals it was found that the best transformation was the logarithmic one $(i.e. \; \lambda \approx 0)$.

[8] This information comes from the Society of Taxation CATSA, and is used for purposes of scientific research by the Centre of Land Policy and Land of the UPC.

containing the price of real estate transactions, the value stated in appraisals is considered a good indicator of the market price (Roca, 2005). Besides, each appraisal must be, at least, endorsed by 6 "witnesses" for actual transactions. In any case, the bias normally introduced by real estate cycle is assumed that randomly affects the whole mass of appraisals done in the same time period, as well as the biases introduced by appraisers.

Table 2 summarizes descriptive statistics of used covariates[9]. In the *S* dimension there are covariates and factors relating to structural features of flats such as: built area, constructive quality, etc.; the quality of the windows is used as a proxy for the level of soundproofing, since the best quality windows often incorporate hermetic seals and double glazing. On the *A* dimension there are the following indicators of accessibility: subway stations, suburban rail stations, bus stops, journey-to-work time, distance to CBD, density and diversity[10] of employment and services, and an indicator of households accessibility perception[11].

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[9] The descriptive statistics refers to the sample used, see further how that sample has been selected.

[10] The diversity has been calculated using the Shannon's entropy equation:

$$H = \sum_{i=1}^{n} -1 * P_i * Ln(P_i)$$

Where *P* is the probability to find an *i* activity from the existing *n* in every zone.

[11] This information refers to % of households, at census tract level, which stated in the 2001 National Census that their houses were poorly communicated.

**Table 2. Descriptive statistics of selected variables for sample used in models.**

| | N | Minimum | Maximum | Mean | Std. Deviation | Source |
|---|---|---|---|---|---|---|
| **Structural (S)** | | | | | | |
| Total price (Euro) | 2498 | 81,220 | 1,201,625 | 279,171 | 127,200 | a |
| Sq. m. price (Euro/sq.m) | 2498 | 2,032 | 8,453 | 3,502 | 593 | a |
| Gross area (Sq.m) | 2498 | 23 | 220 | 84.23 | 25.76 | a |
| Bedrooms | 2498 | 1 | 7 | 2.88 | 0.87 | a |
| Bathrooms | 2498 | - | 7 | 1.28 | 0.54 | a |
| Bathrooms /bedrooms | 2498 | - | 3 | 0.48 | 0.23 | a |
| Gross area (Sq.m.) /bedrooms | 2498 | 11 | 85 | 30.88 | 10.10 | a |
| Windows quality | 2498 | 1 | 5 | 3.05 | 0.62 | a |
| Bath's finishes quality | 2498 | 1 | 5 | 3.06 | 0.59 | a |
| Kitchen finishes quality | 2498 | 1 | 5 | 3.06 | 0.65 | a |
| Age (years) | 2498 | - | 155 | 31.81 | 28.30 | a |
| Individual heating (1=yes) | 2498 | - | 1 | 0.19% | 4.40% | a |
| Central heating (1=yes) | 2498 | - | 1 | 51.24% | 49.99% | a |
| Lift (1=yes) | 2498 | - | 1 | 37.56% | 48.44% | a |
| **Accesibility (A)** | | | | | | |
| Travel to work time (min.) | 2498 | 19 | 38 | 27.54 | 2.92 | b |
| Distance to CBD (m.) | 2498 | 76 | 5,922 | 2,885 | 1,237 | e |
| % poorly communicated households | 2498 | 1% | 67% | 11.16% | 13.06% | b |
| Employment & service Shannon's diversity | 2498 | 2 | 4 | 3.07 | 0.28 | c |
| Employment & service density (Registers/Sq.km) | 2498 | 76 | 8,723 | 2,570 | 1,496 | c |
| Bus stops / 1000 people | 2498 | - | 96 | 2.48 | 4.11 | d |
| Subway entrances /1000 people | 2498 | - | 20 | 0.27 | 0.69 | d |
| Suburban railway entrances /1000 people | 2498 | - | 3 | 0.01 | 0.09 | d |
| **Neighbourhood (N)** | | | | | | |
| % Managers | 2498 | 2% | 27% | 8.82% | 3.92% | b |
| % Professionals | 2498 | 4% | 39% | 17.14% | 8.61% | b |
| % Tecnhnicians | 2498 | 6% | 21% | 16.22% | 3.05% | b |
| % Clerks | 2498 | 7% | 18% | 13.16% | 2.02% | b |
| % Salesclerks | 2498 | 6% | 27% | 15.76% | 3.68% | b |
| % Qualified blue collar (manufacture) | 2498 | 2% | 23% | 11.29% | 4.62% | b |
| % Non qualified blue collar (manufacture) | 2498 | 1% | 20% | 7.58% | 3.32% | b |
| % Non qualified (other sectors) | 2498 | 3% | 23% | 9.60% | 4.08% | b |
| % dwellings with caretaker | 2498 | 0% | 59% | 6.93% | 8.09% | b |
| University graduate | 2498 | 3% | 43% | 16.57% | 8.59% | b |
| Average dwelling's net area (Sq.m) | 2498 | 30 | 144 | 73.17 | 13.29 | b |
| **Environmental (E )** | | | | | | |
| % Noise annoyed households | 2498 | 20% | 63% | 43.21% | 7.20% | b |
| % Smell annoyed households | 2498 | 8% | 52% | 26.43% | 7.42% | b |
| % households in a poor greenery area | 2498 | 6% | 73% | 38.88% | 14.94% | b |
| % disrepaired dwellings | 2498 | 0% | 64% | 6.28% | 6.57% | b |
| % Beach and water | 2498 | 0% | 10% | 0.09% | 0.69% | f |
| Landscape Shannon's diversity | 2498 | 0 | 2 | 1.49 | 0.27 | f |
| % Manufacturing activity | 2498 | 5% | 41% | 17.03% | 5.84% | c |
| Noise (dB A Leq) | 2498 | 50 | 80 | 68.38 | 5.12 | g |

Own estimations using data from:

a) Valuation database (2005)
b) Dwelling & Population Census INE (2001)
c) IAE Economic Activity Tax (2002)
d) Metropolitan Transports of Barcelona (2005)
e) GIS own estimation (2005)
f) Own remote sensing on SPOT satellite imagery (2002) futher details about remote sensing process can be seen in Alhaddad *et al* ., 2006
g) City council Sonic Map (1997)

In the *N* dimension there is information related to socioeconomics: the presence of doorman in the building, percentage of population with university education, percentage of unemployed people, percentage of employed managers, percentage of professionals and dwelling average size in the on the context. In the *E* dimension the covariates are related to the environmental quality: the environmental noise level (dB A Leq), the households perception in relation to the presence of bad odours and lack of green areas, percentage of dwellings in ruined or in bad condition, average construction year of the neighbourhood`s houses, land use, percentage of industrial economic activities, diversity of the land use covers (as proxy for the landscape diversity).

The information sources are detailed above in the Table 2 and the smallest geographical units with available data were:

1. Flats: individually geo-referenced (3,196)
2. Census data: census tracts (1,498)
3. IAE information: statistical study zones from City Council (248)
4. Land use satellite information: census tracts (1,494)
5. Acoustic map: individually geo-referenced sonometric points (1,045)
6. Bus, subway, rail, stops/stations: individually geo-referenced (4,565)

Using GIS aid the non structural attributes data have been transferred to dwellings. For this reason it has been used different buffers 300, 600 and 900 meter in radius (mr), as it has been done by Acharya & Bennett (2001). The model presented in this paper is built up using data for the buffer 300 mr.

As a preliminary step, besides to remove 604 apartments without sonometric data, there has been eliminated all the apartments with an extreme value on their attributes than locate them far from what can be considered as a "standard" flat. For the purpose of considering at the same time all the dwellings attributes in the filtering process, it has been use the Mahalanobis Distance (MD). Beyond its statistical robustness[12], according to Li *et al*. (2005), the MD allows to remove those flats whose prices are not explained by the covariates but for other aspects not measured, for example, the fact that the expensive houses have "*finer decorations and fixtures, floor coverings and landscaping*" (p. 3), or specific insulation against noise pollution. *The elimination of the cases linked to the influence of omitted variables is crucial, since they can bias the models regression coefficients, and therefore shed inefficient estimates on the noise hedonic function* (Bateman, *et al.,* 2001).

The MD was calculated using those covariates and factors which, in statistical terms[13], were explaining the value of the apartments. Fig. 3 summarizes the results, in the horizontal axis the houses are expressed in percentile terms on the left vertical axis is the MD, and on the right is

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[12] These properties are: robustness to the multicolinearity and the difference in the scale of covariates. The MD is calculated as follows:

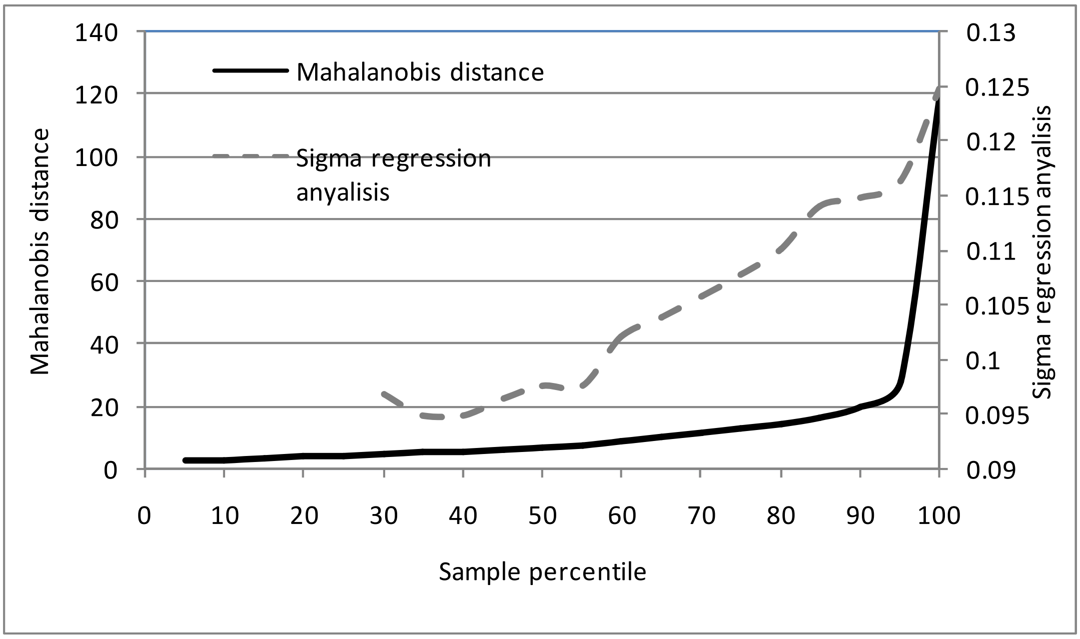
$$D^2 = (X - M_x)' \sum_x^{-1} (X - M_x)$$

Where *D* is the MD, *X* are the attributes of housing, and *Mx and Σx* is the variance-covariance matrix.

[13] For this propos it has been built a stepwise OLS model introducing those covariates with p-values lesser than 0.05. Therefore the MD refers to the following covariates: gross area, PC1 (1 of a principal component factor analysis used to synthesized the socioeconomic structure, see details below), gross area ^ 2, % manufacturing activity, % beach and water, central heating dummy, travel to work time (min.), gross area (sq.m) / bedrooms, Employment and services density, % road surface, Noise level (dB A Leq), regular and low quality windows dummies.

the standard error (sigma) of each OLS model considering only the cases which their MD is lower than indicated. As it can be seen, as the sample is reduced (i.e. the most extreme cases are progressively eliminated) the standard error of corresponding models is also reduced. This process also progressively increases the properties N (0.1) of residuals which is desirable when calibrating using OLS. Note that the efficiency of the models stop rising below the percentile 50.

**Figure 3. Mahalanobis distance and model´s sigma.**




As it is shown in Fig.3, the curves of the MD and the sigma of its corresponding model, experiment the most drastic fall between 100 and the 95 percentile; for this reason, we have decided to work with the cases below that threshold (28.10 DM), which led to the elimination of 5% of the apartments farther away[14], in all its attributes, the apartment of "average characteristics.

# 4. - Results.

Table 3 (left), reports the results of the best OLS model, in terms of adjustment, multicolinearity absence, normality and homocedasticity of residuals. This model is able to explain in 89.5% the values of the sample of apartments. The signs of all covariates are the expected, and its coefficients are significant at 95% of confidence. According to that model in the *S* structural features dimension stand out, besides the built-up area, the square of the built-up area (which internalize the principle of diminishing returns), some quality indicators

[14] However models were built with the 50,55,65,70,75,80,85 and 90% of the sample, showed consistent results regarding the hedonic noise function.

such as the ratio between the built-up area and the number of bedrooms, which besides being a indicator of interior spaces generosity, is a proxy for other aspects related to apartments quality. Also, are included the dummies which internalize the windows quality[15], the coefficient of the dummy "regular quality Windows" is -0.043, and as expected, the coefficient of the dummy "low quality Windows" is -0.078. This suggests that those apartments having aluminium, PVC, double glazed and hermetic seals windows enjoy a market premium because, among other things, they offer a reasonable thermal and acoustic insulation, which is brought directly to the households budget and improve their comfort level, affecting both their implied WTP. Finally it is significant the inclusion of central heating dummy with positive sign, it is important to note that this variable also represents, in part, the age of the buildings since oldest buildings don't have it.

On the accessibility dimension *A*, it is include the journey-to-work time, with the expected negative sign, and the density of jobs and services (which represents access to convenience shops and services). *Ceteris paribus*, for every minute that journey-to-work increases, the value of apartments fall by 0.57% and the standardized beta-coefficient -not reported in Table 3 - (calculated on the z-values of the covariates) suggests that it is more important to be located few minutes away from workplace than in an area with a high density of services. In the *N* dimension of the socioeconomic neighbourhood characteristics it is include the Principal Component 1 (PC) from a factor analysis built on the percentage of households classified according to the occupation of their householder. Such a factorial analysis summarizes in 2 axes the socioeconomic structure of the city, and explains 84% of the variance of the 9 original variables. In particular the PC 1 is able to explain 67% of the variance and polarize, on one end (with positive factor loadings) low-income classes (e.g. unskilled workers), and at the other end (with negative factor loadings) high-income groups (e.g. managers and professionals). In this way the PC 1 enters with the expected negative sign. *As a matter of fact, of all exogenous variables considered, according to the standardized beta coefficient, this locative attribute has the greatest influence on the price, which not only indicates the wealth of the residents, but also the market premium that they are willing to pay for flats located in most prestigious areas of Barcelona* (Roca, 1983).

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[15] It is important to note the positive correlation of this variable with others relating to the quality of the finishes of the bathrooms and kitchen and amenities such as central heating. Therefore, the quality of the windows is also a proxy for the overall quality of dwellings.

## Table 3. Estimations for OLS and Spatial Lag Models

| | OLS model | Max. likehood spatial lag (SL) |
|---|---|---|
| S-squared | 0.896 | 0.902 |
| S-squared adjusted | 0.895 | 0.901 |
| Sigma (std. error) | 0.116 | 0.112 |

| Variable | OLS model: Unstandardized coefficients | | | Max. likehood spatial lag (SL): Unstandardized coefficients | | |
|---|---|---|---|---|---|---|
| | B | Std. error | Sig. | B | Std. error | Sig. |
| W_LN total price (Euro) | | | | 0.254 | 0.020 | 0.000 |
| Intercept | 11.600 | 0.063 | 0.000 | 8.319 | 0.268 | 0.000 |
| Gross area (Sq.m) | 0.018 | 4.1E-04 | 0.000 | 0.018 | 3.9E-04 | 0.000 |
| PC1 (low income households) | - 0.081 | 3.9E-03 | 0.000 | - 0.033 | 5.3E-03 | 0.000 |
| Gross area (Sq.m)^2 | -3.6E-05 | 1.9E-06 | 0.000 | -3.9E-05 | 1.9E-06 | 0.000 |
| % Manufacturing activity | - 0.308 | 0.059 | 0.000 | - 0.161 | 0.058 | 0.006 |
| % Beach and water | 2.384 | 0.348 | 0.000 | 1.948 | 0.338 | 0.000 |
| Central heating | 0.029 | 0.005 | 0.000 | 0.024 | 0.005 | 0.000 |
| Travel to work time (min.) | - 0.006 | 1.3E-03 | 0.000 | - 0.004 | 1.2E-03 | 0.002 |
| Gross area (Sq.m.) /bedrooms | 0.001 | 2.5E-04 | 0.000 | 0.001 | 2.4E-04 | 0.000 |
| Employment & service density | 6.8E-06 | 2.5E-06 | 0.006 | 5.9E-06 | 2.4E-06 | 0.013 |
| % Road surface | - 0.053 | 0.020 | 0.009 | - 0.080 | 2.4E-06 | 0.000 |
| Noise (dB A Leq) | -1.4E-03 | 6.0E-04 | 0.019 | -9.3E-04 | 5.8E-04 | 0.100 |
| Regular quality windows | - 0.043 | 0.008 | 0.000 | - 0.041 | 0.007 | 0.000 |
| Low quality windows | - 0.078 | 0.019 | 0.000 | - 0.079 | 0.018 | 0.000 |

**ANOVA**

| | Sum of Squares | df | Mean Square |
|---|---|---|---|
| Regression | 287.6312681 | 13 | 22.13 |
| Residual | 33.38968005 | 2,484 | 0.01 |
| Total | 321.0209481 | 2,497 | |

| | |
|---|---|
| Threshold dist. (m) | 375 |
| Log likelihood | 1,923 |
| Lag. Coeff (Rho) | 0.254 |

| F | Sig. |
|---|---|
| 1,646 | 0.000 |

Dependent variable: Ln total price (Euro)
OLS stepwise method

In the last environmental dimension *E* are included three covariates, firstly the percentage of manufacturing activities in the housing area (including workshops and repair garages situated on the ground floors and in the buildings yards). Secondly, with positive sign the percentage of beach and water in the environment, of course, this refers basically to homes located in the coastal area (i.e.: the Villa Olimpica), but also, thanks to the relatively high resolution (1 pixel = 2.5 m) of the satellite imagery used in remote sensing process, this attribute proxies for the swimming pools of luxury developments (e.g. Pedralbes), and in a lesser extent, the fountains (e.g. Plaça Espanya) and public swimming pools (e.g. Vall d'Hebron). *It is worth to say, that the waterfront renewal at Barcelona (which opened the city to the sea) has represented a significant impact on the historic structure of residential values* of this city (see since Roca, 1983). Thirdly, with negative sign the % of streets that surround the houses is included, this indicator proxies for other externalities associated with vehicular traffic, as it has been demonstrated, is the main source of noise pollution. Such externalities relate to atmospheric emissions, vibration, and interference on the public space created by the presence of major roads. Finally, the last significant environmental variable is the intensity of the sound. The suggested impact by the coefficients B and Beta is small when it's compared with the NDSI reported by other investigations (see Section 2). According to OLS model and considering data limitations[16] NDSI is 0.14%, it means that, remaining everything else constant, the value of apartments reduces this percentage for each dB that noise increases. In addition, the p-value of this covariate is greater than any other, suggesting greater uncertainty in the coefficient estimation; we are coming back on this issue later.

Residuals spatial analysis indicates the presence of autocorrelation (Moran's I = 0.0507), it may be produced, by externalities exerted mutually among dwellings, which have not been successfully internalized by the independent variables (Can 1992; Nelson, 2008). In an attempt to reduce this problem there has been constructed an autoregressive spatial model (Anselin, 1995, 1998, 2008). After the spatial-lag calibration (Table 3, right), the model fit increases slightly, reaching 90.1% of the explanation of the variance in the Ln value. All the variables maintain their sign but some coefficients vary slightly, e.g.: social structure indicator reduces its importance, as well as the percentage of manufacturing activity, the percentage of water-beach, and the percentage of streets in the environment increases. In contrast, all other variables "maintain" their coefficients. The relatively high standard error of noise, which leads to a relatively high significance (located on the edge of the 90% confidence) might suggest that this externality does not have a linear impact throughout the residential area of Barcelona. In the next section this hypothesis is explored in depth.

## 4.1 A non-stationary impact of noise on the spatial formation of residential prices.

In addition to spatial dependence problems (i.e. spatial autocorrelation), spatial heterogeneity is another issue to be resolved when implementing HP method, since it may affect the accuracy and significance of OLS estimations which assumes a spatially-invariant or stationary set of coefficients (Can, 1992; Fotheringham *et al*., 2002; Paez *et a*l., 2008). Such heterogeneity refers to the unequal influence that intrinsic and extrinsic attributes have on the explanation of residential values, with regard to the possible existence of submarkets. In this framework it would be plausible to expect that noise affects differently the hedonic function of apartments that belong to different submarkets because, either have different constructive attributes and architectonic programs like large terraces or community spaces inherently exposed to noise

[16] These results are just an Approximation a while, despite efforts, has not been possible to achieve the ultimate acoustic map of the city. However, comparing the maps of 1990 and 1997 suggests that the overall structure of the noise is kept, plus the large urban transformations, with the exception of the Forum of Cultures, 2004, were made at the time of the 1997 map. This coupled with the relative inertia in the mechanism of formulation price in real estate (Bateman, et al., 2001) gives some assurance of the approximation in this investigation.

pollution (Marmolejo & Romano, 2009), or the sensitivity of its users is different (Kuno *et al*., 1993; Daumal, 2001; Kestens *et al*., 2006). So, the implicit price of 1 dB would have, from the theoretical perspective, not to be the same in different market segments or in different locations inherently subject to different noise levels. Consequently for each submarket there should be a specific hedonic function (Rosen, 1974). Despite this, in practice the HP method, can yield to similar structurally equations since it focuses on the price of the attributes and not on the amount of available attributes on the dwelling (Bourassa, *et al*., 2003). So although the F-Chow test which analyses residuals, or the Tiao-Goldberg F-Test which analyses coefficients, indicate structural similarity it may be the case that the dwellings are not actually in the same submarket.

Beyond the qualitative approaches to identify submarkets carried out by experts (e.g. realtors or appraisers) in the literature there are statistical alternatives. Like, the quite popular, factor analysis (e.g. Dale-Johnson, 1982), followed by cluster analysis (Maclennan & Tu, 1996; Bourassa *et al*., 1999; Bourassa *et al*., 2008) to find areas with homogeneous attributes ; up to the most innovative based on the analysis of price´s elasticity (Pryce, 2008), to find areas with interchangeable dwellings. Each approach can be valid according to the purpose of the analysis. However, with few exceptions (see Bourassa, *et al.*, 2003), almost all have failed to conceptualize submarkets with clearly defined borders; this assumption in some cities is as unrealistic as administrative boundaries. This is the particular case of Mediterranean cities (compact and diverse) in Europe, characterized by "smooth transitions" between different urban fabrics. In addition, from the econometric perspective, the "hard" borders prevents for considering the externalities that one zone exerts over others (i.e. space dependencies) when models are calibrated separately for each zone. In this context following the conceptual proposal of Paez *et al.* (2008) it seems plausible to think in submarkets with faded borders, allowing the consideration of spatial interactions between them. One method suitable to deal with such kind of borders is the geographically or locally weighted regression GW-or-LWR (Brundson *et al*., 1996; McMillen, 1996; Fotheringham, *et al*., 2002), which also solves space dependency issues (Paez *et al*., *Op. Cit*.).

In general GWR adjusts as many regressions as observations are present in analysis. In these regressions the weight (i.e importance) of the observations, on the estimation of the B parameters, decreases as further they are located from the pivoting point (one different for each regression). The weighting matrix is calculated as follows:

$$w_{ij} = \left\{1 - \left(\frac{d_{ij}}{h_i}\right)^2\right\}^2 \; if \;\; d_{ij} < h_i \; otherwise = 0 \qquad (3)$$

Where *w* is the weighting space matrix, *i* is the pivotal point of the regression, *j* is each of the *N* observations included in the local regression and *h* is the distance from the Nht *j* point (Charlton *et al.,* 2005). When the density of the observations is not constant throughout the space the use an adaptive kernel is convenient, which also allows to relax the geometry of the analysis area, which may not be isotropic from the point *i*. The results of the GWR using an adaptive kernel with 628 crossvalidated cases are contained in Table 4. The adjust increases up to $R^2$ of 0.91, besides the Akaike Information Criterion and the reduction of sigma suggest that the locally weighted regression model overscores significantly the OLS and the Spatial-lag. The summary of the distribution of the coefficients are expressed in terms of upper and lower quartiles and the Huber's M-estimator provides a robust average (see Huber, 1981). Compared to OLS model Huber's M-estimators of Table 4 are quite similar with few variations, for example, the negative influence of manufacturing activities on residential values decreases, at the same time that decreases the positive influence of water & beach. In addition noise coefficient is reduced slightly (from 0.0014 to 0.00083). Taking the average price of the apartments on the sample used and the noise's M-estimator it is inferred that their value is reduced on average 232.61 Euros for each dB that surrounding noise increases.

Table 4 also shows the percentage of local estimations in which the covariates coefficients are significant at 90% confidence. As it can be observed, noise and beach-water show the lowest proportion of significant regressions, which endorses the relatively high *p-value* of noise in the models from Table 3 (0.019 for OLS and 0.10 for SL).

*It's worth to say that, virtually all variables have a not stationary impact on value. It means that the marginal value of each unit of each attribute fluctuates throughout the space.* Likely this is the reason beneath the good performance of GWR model, since it considers the specific local relationships between the price and localized attributes. In order to statistically validate the spatial variation of local factors a Monte Carlo test has been performed (Fotheringham, *et al.*, 2002). Results (Table 4 right) suggest that all covariates, with the exception of the quality of flats (i.e. built area/bedroom and windows quality) and the accessibility indicator, have statistically different impacts on the price of apartments throughout the space.

**Table 4. Estimation for GWR model**

| **GWR Model** | |
|---|---|
| S-squared | 0.915 |
| S-squared adjusted | 0.911 |
| Sigma (std. error) | 0.108 |

| Akaike information criterion | | |
|---|---|---|
| OLS | - | 3,678 |
| GWR | - | 3,935 |

**B distribution statistics** / **Significance tests**

| | Lower quartile | Huber's M-estimator | Upper quartile | Local regressions with pseudo-p-value <0.10 | Monte Carlo Test for spatial variability (p-values) | |
|---|---|---|---|---|---|---|
| Intercept | 11.143 | 11.452 | 11.687 | 100% | 0.000 | *** |
| Gross area (Sq.m) | 0.018 | 0.020 | 0.021 | 100% | 0.000 | *** |
| PC1 (low income households) | - 0.118 | - 0.081 | - 0.053 | 100% | 0.000 | *** |
| Gross area (Sq.m)^2 | -5.4E-05 | -4.7E-05 | -3.7E-05 | 100% | 0.000 | *** |
| % Manufacturing activity | - 0.790 | - 0.261 | 0.181 | 58% | 0.000 | *** |
| % Beach and water | - 4.320 | - 0.088 | 1.845 | 21% | 0.000 | *** |
| Central heating | 0.011 | 0.018 | 0.026 | 41% | 0.020 | *** |
| Travel to work time (min.) | - 0.007 | - 0.004 | - 0.001 | 23% | 0.110 | n/s |
| Gross area (Sq.m.) /bedrooms | 2.4E-04 | 8.9E-04 | 1.5E-03 | 47% | 0.240 | n/s |
| Employment & service density | 3.0E-06 | 9.6E-06 | 1.6E-05 | 42% | 0.000 | *** |
| % Road surface | - 0.122 | - 0.052 | 0.005 | 33% | 0.000 | *** |
| Noise (dB A Leq) | -2.9E-03 | -8.3E-04 | 1.4E-03 | 17% | 0.000 | *** |
| Regular quality windows | - 0.059 | - 0.044 | - 0.028 | 74% | 0.350 | n/s |
| Low quality windows | - 0.104 | - 0.074 | - 0.045 | 50% | 0.460 | n/s |

*** sig. at 0.1% level
n/s not significant

**ANOVA**

| | Sum of Squares | df | Mean Square |
|---|---|---|---|
| OLS Residuals | 33.38 | 14 | |
| GWR Improvement | 6.08 | 108 | 0.06 |
| GWR Residuals | 27.3 | 2,375 | 0.0115 |

| | |
|---|---|
| N nearest neighbours | 628 |
| Num. locations to fit | 2,498 |

| F | Sig. |
|---|---|
| 4.917 | 0.000 |

Dependent variable: Ln total price (Euro)
GWR Adaptative kernel crossvalidated

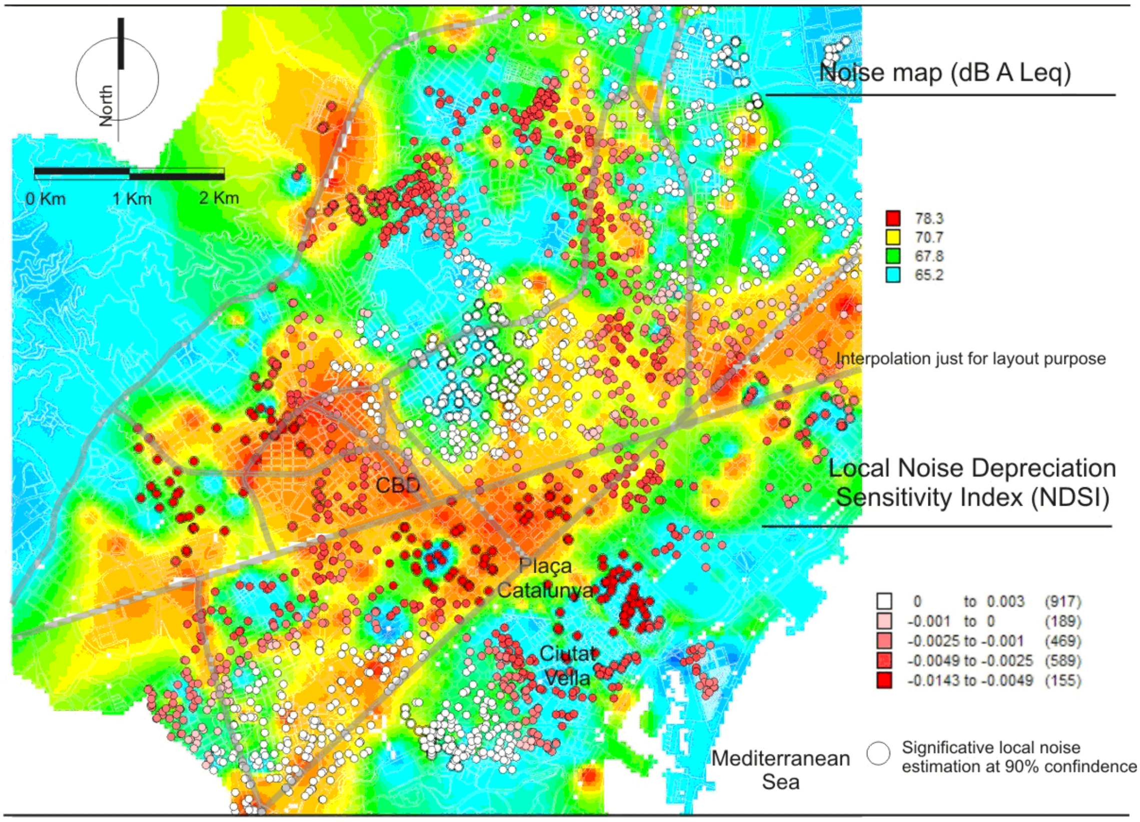
Remarkably, according to GWR, noise has negative and positive impacts in different parts of the city. If we consider just regressions in which the noise coefficient is significant at 90% of confidence the NDSI´s bottom decile is -0.0081 while the top decile is +0.0054. It is to say, in the bottom 10% of the regressions for each dB noise increases dwellings price is reduced by 0.81%, while paradoxically in 10% top cases the price increases by 0.54%.

The simple visual inspection of noise´s local coefficients, and "local knowledge", allow hypothesizing the nature of this paradox (Fig. 4). Firstly, there is a clear relationship between the noise level and the impact of each dB on residential values. As a matter of fact, the correlation between the noise B coefficient (for regressions significant regressions) and the level of environmental noise is negative (r =- 0.404) and a significant at 99% of confidence, i.e.

the higher the noise level, the deeper its negative impact on values per dB. But this relationship is not continuous, as shown in regressions (statistically significant) where the noise seems to have a positive impact are located in areas with intermediate levels of noise. That is why the average NDSI for the observations located between the intermediate range from 70 to 75 dB is +0.0026; while the NDSI average for the observations located in the inferior range of 65-70 is negative -0.0014; and for those located in the upper range of 75-80 dB the NDSI is even more negative -0.0040. The paradox could be resolved if one considers that these areas of intermediate noise are located near to the areas of maximum noise, being these latter the most important points of provision of transport and services in the city, *so the apparent positive correlation may actually be proxying for a privileged access to such services.* Therefore, it seems there is a market premium by gaining access to services and transportation rapidly but without suffering the highest levels of noise from the roads on which they are located. This same conclusion has been reached by Day (2003) to find a positive sign for the noise in one of the 4 submarkets identified in Glasgow.

Fig. 3 also shows that some pedestrian areas with relatively low noise levels, like the Barcelona's Historic Centre (Ciutat Vella and Raval), have hedonic functions similar to those vehicular areas with higher noise level (this is why the NDSI is negative in the lower 65 to 70 dB range). Which suggests that the sonic intensity measured by sonometers is not enough fully capture the dimension of noise; since it only records one of its aspects: the intensity. So residents living in urban areas where noise comes, as in the Ciutat Vella and Raval, from pedestrian traffic (mainly leisure), restaurant´s terraces, pubs and open space public manifestations, seem to have a special sensitivity against noise (and other externalities), which further produces a greater appreciation on property values for each dB of peace and quietness gained.

**Figure 4. Noise map and noise's hedonic pricing local estimations.**




## 4.2 Hedonic pricing versus willingness to pay for noise reduction in Barcelona.

In 2006 Marmolejo & Frizzera (2008) conducted a CV study in Barcelona to research resident`s WTP to improve the city´s quietness. Namely, 405 households were face to face interviewed to know whether and how much they were willing to pay for a noise abatement equivalent to "reduce the sonic levels from a working day´s rush hour up to a sonic level similar to that experienced on the same day but at 21:00" (p. 27). Next it was explained that all citizens would finance the project paying a monthly tax for person (without explaining how long the tax would be charged). WTP averaged 3.25 (in 2006 values) Euro/person/month which, according to the authors, is approximately 0.28% of average household´s gross income, a proportion coincident with an analogous study conducted in Spain by Barrereiro *et al.* (2005) for a similar noise reduction in Pamplona. Analyzing the noise variation along the day recorded in the Barcelona´s Acoustic Map, it can be assumed that the reduction offered by the authors is approximately 3.21 dB, which means that households are WTP 2.53 Euro/dB/household/ month (financially equivalent to 30,99 Euro/dB/household/year) considering 2.5 persons per household.

The WTP found by Marmolejo and Frizzera (*Op. cit.*) is a monthly payment equivalent to the surcharge that households would be willing to pay for enjoying a quieter dwelling in a rental market. The results of our study, as noted above, suggest that the reduction in 1 dB noise level represents an increase in sales value of 232.61 Euros, to transform this sale value in rental value it is possible to use the specific yield for the residential rental market in Barcelona. In this way, using a market yield of 4%, the equivalent rent surcharge for a quieter flat would be 0.76 Euro/dB/ household/ month (9.30 Euro/dB/household/year).

As it can be see the WTP for 1 dB is significantly higher than the implicit price found by the HP method (WTP/HP ratio = 3.33), which differs from other studies (Pommerehne, 1988; Soguel, 1994, 1996; Vainio, 1995, 2001; Bøjrner, 2003) but, instead, is consistent with the theoretical approach of Feitelson *et al.* (1996) summarized in Fig. 1 and with the early studies reviewed by Verhoef (1994). Furthermore, It is likely that the WTP found by the CV method is internalizing the noise impact on quality of life in spaces beyond houses (e.g. public spaces not necessarily adjacent to housing).

## Conclusions.

Several hedonic pricing studies have assessed the impact of noise on the formation of property values (see the excellent reviews conducted by Bateman *et al.*, 2001; Navrud, 2002; Bøjrner, 2003; and Nelson, 2008). Most of them have successfully proved that welfare lost produced as a consequence of noise increment negatively impacts on the dwellings values, indexing such an impact by means the NDSI (Noise Depreciation Sensitivity Index).

Studies conducted in different cities suggest that NDSI varies largely, for example, those reviewed by Navrud (*Op. Cit*) for vehicular traffic noise indicate that NDSI ranges from 0.08% to 2.2% with an average 0.64% (i.e. for each dB the noise increases, price decreases 0.64%). From the theoretical perspective this variation *among* cities is not surprising since each market has its own hedonic schedule that depends on their socio-economic and structural characteristics. However, it is expected that the NDSI also fluctuates *within* the cities that have diversified real estate markets characterized by the existence of submarkets. In this context studies as these conducted by Becker & Wash (2003), and Baranzini & Ramirez (2005) have reported that noise is more penalized in areas where, per excellence, it is expected to be silent (e.g. suburban countryside areas); on the other hand, Collins & Evans ( 1994) and Rich & Nielsen (2004) have reported different penalisations between flats and houses (more penalised for detached houses), at the same time, Day (2003), Bateman *et al.* (2004) and Day *et al.* (2007) have reported statistically significant variations between NDSIs belonging to different submarkets detected through multivariate techniques. Nevertheless theses latter studies have considered submarkets clearly demarcated by “hard borders”. In the case of the Mediterranean cities (compact and diverse), this could represent a problem since there are smooth transitions between the different urban fabrics. In this line Paez *et al.* (2008) have suggested the use of mowing window regressions, which can be conceptualized as sliding neighbourhoods (i.e. soft market segmentations) that can incorporate spatial dependency effects. In this paper we use locally or geographically weighted regression (GWR or LWR) (Brundson *et al.*, 1996; McMillen, 1996; Fotherigham, *et al.*, 2006) to find whether or not the impact of noise is stationary on the spatial formation of Barcelona’s residential market.

GWR approach is able to explain 91.1% of values variation of 2,498 apartments sample (once debugged using the Mahalanobis distance). Model´s coefficients suggest that after controlling for the flat's structural attributes (e.g. size and quality), neighbourhood (e.g. socioeconomic status) and accessibility (e.g. journey-to-work time) the noise does matter on the spatial formation of real estate values. The adjustment of GWR model excels the results of both OLS and Spatial-lag models ($R^2$= 0.89 and 0.90 respectively), suggesting not only the existence of spatial dependencies (resolved by the autoregressive model), but mainly, the spatial heterogeneity (i.e. the unequal influence that intrinsic and extrinsic attributes have on property prices, and consequently, the existence of submarkets).

The results of a Monte Carlo validation confirms that NDSI has a non-stationary influence throughout the city. Those areas with higher levels of noise (e.g. those located along the main avenues) are also those in which the NDSI has a deeper negative impact; but it also occurs in the relatively quiet pedestrian city centre (Ciutat Vella and Raval) characterized by a significant presence of bars, restaurants, terraces and pedestrian traffic; in this latter case we hypothesize that such a negative impact may be associate to the negative perception of local residents about such leisure activities which not only produce noise, but other externalities. *So the intensity and nature of noise's source may be behind the not stationary character of noise impact on real estate values.*

*The average NDSI (calculated by means of the Huber M-estimator considering 2.498 local estimations) is 0.083%, which situates the Barcelona's market (the submarket) in the bottom decile of all studies reviewed by Navrud (2002).* In monetary terms it can be said that for every dB A Leq that the noise increases in Barcelona the average sale value of apartments is reduced in 232.61 Euros, equivalent to a rent reduction of 9.30 2006-Euro/dB/dwelling/year, considering a yield of 4%. This result is significantly lower than the WTP derived from an equivalent CV study conducted by Marmolejo and Frizzera (2008), equivalent to 30.99 2005-Euro/dB/household/year. This could indicate that the respondents in their study not only assessed the impact of noise on residential comfort, but also, the negative interference on the habitability of other public spaces as not necessarily located next to their home (e.g. streets and parks ). Also in the line of the discussion initiated by Feitelson *et al*. (1996) this finding reinforces the idea that the implicit price of silence in the housing market differs from the WTP of CV, given that both curves have different slopes as explained in Fig. 1.

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