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Technical note

A new indicator to measure the noise impact around airports: The Real Estate Tolerance Level (RETL) – Case study around Charles de Gaulle Airport

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ABSTRACT

The Community Tolerance Level (CTL) is a new indicator which characterizes the impact of aircraft noise around local airport. It corresponds to the exposure sound level (DENL or DNL) where 50% of the population is highly annoyed. Inspired by this indicator, this paper aims at calculating the Real Estate Tolerance Level (RETL) which corresponds to the exposure sound level where a property price is 50% depreciated compared to the price of the same property which would be situated in an area whose DENL is below 50 dB(A). The use of a notarial database analyzed with the Hedonic Price Model (HPM) made it possible to calculate the percentage of property price depreciation around CDG airport, with 1-dB steps of DENL, and so far to calculate the RETL. 19,891 house transactions and 23,264 apartments have been localized with a Geographic Information Systems (GIS) and crossed with the Sound Environment Curves provided by Airport of Paris. The RETL value for single houses and for apartments around CDG is 75.8 dB. It is comparable to the mean CTL value which has been estimated to 73.3 dB from the DNL data of 43 airports over the world (about 73.9 dB from DENL data). The RETL is predictable without field survey and could characterize the impact of aircraft noise around local airports. It could be a good indicator to follow the evolution of population tolerance over the years.

1. Introduction

In a context of continuous growth of airport activities, the link between objective acoustic measurements and population noise exposure still remains an issue for public stakeholders and researchers. In the transportation field, Miedema dosage–response curves are used to quantify the exposed population to noise (percentage of annoyed or highly annoyed people) [1,2]. These curves are based on DENL or DNL, and are approximated with polynomial models which accounted for 44% of variance [3]. The relevance of these curves is discussed today because the data which has been used to build the models was collected between 1960 and 2000. It seems that nowadays, people are more annoyed by noise than the Miedema had predicted [4,5]. Moreover, these curves correspond to a best-fit model based on annoyance data collected around different airports in Europe, North America and Australia, using different methods. Consequently, there may exist a bias in comparing and mixing the data [6]. A recent idea consists in working on a local indicator which characterizes the impact of noise around each airport and which better fits to populations' local reactions. The predicted impact follows a sigmoid model. The inflection point where 50% of the population is highly annoyed corresponds to the local indicator (the Community Tolerance Level – CTL), and is specific to the community of people who lives around each airport [7]. The advantage of the CTL is that it is modestly correlated to DNL. So, when adding this local indicator to DNL in a multiple regression, the model accounts for 66% of variance. The drawback of this CTL indicator is that it is difficult to estimate *a priori*, and still needs field studies to be calculated. Fidell et al. [7] propose to investigate the use of complaint rates in order to predict CTL values in a community. In this paper, the use of property price depreciation is investigated in order to calculate a similar local indicator, which could characterize the impact of

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aircraft noise. This indicator is still not predictable *a priori* before new airport construction, but makes it possible to study local population reactions to noise, avoiding its tiredness because of repetitive field surveys about noise.

So, an indirect way of following population reactions or studying differences between communities is to examine property price depreciation in noisy areas, using the Hedonic Price Method (HPM) [8]. The hedonic price theory is based on the idea that the value of a property can be described through a list of characteristics – such as the number of rooms, the period of construction, the location, the noise level of the environment, etc. The observed price variations for different properties can be accounted for by a variation of these characteristics. Thanks to this hedonic method, it is possible to estimate the impact of each characteristic variation on price, independently from the other characteristics. For noise, the HPM makes it possible to quantify the effect of the environmental sound level on property value, which depends on the probability of being annoyed. In most studies, the load of noise is characterized with the noise exposure level (DENL or DNL) which is defined in terms of equivalent sound level L_{Aeq} with a 10-dB penalty for the night, and a 5-dB penalty for the evening.

With the recent development of Geographic Information Systems (GIS), statistical treatments of environmental quality measurements are made easier. The HPM approach allows an analysis of a huge corpus of data, including several thousands of observations, providing more reliable indications than surveys confined to a few hundreds of households [9].

A lot of HPM studies were carried out at international airports (particularly in the US and in Canada) [10,11]. All these studies, as well as these meta-analyses [12,13], show that despite the dispersion of the results, the conclusion was consistent: aircraft noise mainly has a negative and statistically significant impact on prices [14]. Few studies have been performed in France on price depreciation (see Faburel and Maleyre [15] for Orly Airport, South of Paris), although cost-benefit analyses are useful to justify public policies [16].

A new study was then performed in 2013 for Roissy Charles De Gaulle Airport (CDG, North of Paris). One of the aims of this study was to suggest a new indicator which could characterize the impact of noise and its evolution over time. Originally, the idea consisted in applying the Community Tolerance Level (CTL) approach to the real estate depreciation due to noise. The Real Estate Tolerance Level (RETL) was suggested as a new indicator which could characterize the local impact of noise around each airport.

The following section presents the key assumptions underlying the hedonic model and the statistical method. It develops the hedonic price method theory in order to calculate the price depreciation, while Section 3 focuses on the development of the empirical model applied for this particular study. Section 4 presents the results for the Val d'Oise department: the percentage of property price depreciation due to aircraft noise and the RETL calculation. The results are discussed in Section 5, considering the use of RETL as a noise indicator. The last section presents some conclusions and recommendations for further studies.

2. The hedonic price method

2.1. Hypothesis

The first hypothesis is that aircraft noise affects market prices of residential properties. As highlighted in some research [17,18], damage will be noticed only to the extent that purchasers are aware of it and are able to detect differences in noise between areas. In other words, the noise indicator which is used to communicate with the population in the HPM should correctly characterize the noise exposure and this exposure should influence home buyers or renters when they negotiate a price [19].

In France, there are several public information policies on noise exposure directed at residents or buyers around big airports, particularly through the noise exposure map (*Plan d'Exposition au Bruit* – PEB) [20]. The PEB aims at preventing current or future populations from being annoyed by noise. Thus, the act sets rules to prohibit or limit the possibility of building in areas subjected to aircraft noise. The PEB is based on DENL calculated contours. It sets four noise areas. Two areas have high noise levels (L_{DEN} > 70 dB and L_{DEN} between 65 and 70 dB). One is considered as a moderate area (within the contours [55–65]) and the last one is considered as a low noise area (within the contours [50–55]). Each contract of property sale (or rental agreement) around an airport has to include a clear and legible clause specifying the noise area where the property is located.

In addition, other sources of information are available around CDG airport. In 1996, the Environment and Sustainable Development Centre (*la Maison de l'Environnement et du Développement Durable – MED*) was created at CDG airport (the same as Orly airport). The aim of this specific MED is to provide information on the territorial impact of airports. Resources are available to the public, such as 3D visualization software and interactive multimedia tools. Since October 2006, air traffic controllers provide information hotlines within the MDE twice a week. They answer any questions including ones about noise around airports and flight paths. According to the staff of the CDG MDE, some prospective buyers go to the MED to learn about aircraft noise over their future property. It helps them understand the differences in noise exposure between the areas they visit; so it is likely that all the buyers and sellers are well informed about noise. Nevertheless, one might notice that the DENL indicator might not be the best one to communicate about aircraft noise around airports. Dynamic indicators which focus on flyovers could improve noise understanding [21–24].

Another hypothesis is that the shape of the house price depreciation due to noise follows the same curve as the probability of being annoyed by aircraft noise. It is then likely that a non-linear relationship between noise exposure and price depreciation is appropriate in the urban fringe around airports. Recent studies on the HPM [25] have already shown that the link between noise levels and house prices is not linear. However, the shape of the relationship still remains to be studied [10]. These recent studies also show that the level threshold under which the noise impact can be neglected has to be carefully selected in the models.

2.2. The hedonic price model

The mathematical model is based on a functional relationship between the price of a property, and its characteristics. For this study, the property price is P_i. Characteristics are generally divided into four classes: (1) structural characteristics S_i of the house such as size, number of rooms, etc.; (2) features of the socio-economic neighborhood N_i such as the quality of the school district, the crime rate of the area, the social composition of population, etc.; (3) accessibility characteristics A_i such as the proximity to city center, proximity to employment, etc.; (4) specific environmental amenities E_i such as noise, air pollution, etc. There is always a non-explained part of the price represented by ε_i, a normally distributed error term.

$$P_i = f(S_i, N_i, A_i, E_i) + \varepsilon_i \quad (1)$$

Several basic functional forms such as linear, semi-log, log–log and Box–Cox forms can be applied to the hedonic price model. Linneman [26] found that the Box–Cox transformation cannot be applied to binary or dummy variables. In this study, the linear regression was rejected to focus on nonlinear relationships between real estate prices and noise. As a lot of variables are dummy, only semi-log and log–log functions have been tested, as recommended by Nelson [12]. The log–log function leads to the best statistical adjustment (for single houses R^2aj = 0.74 respectively 0.68 for the semi-log function and for apartments R^2aj = 0.85 for log–log function, respectively 0.80 for the semi-log one. The log–log function can then be written as follows:

$$Ln(P_i) = \alpha + \sum_{j=1}^{J} x_{ij} \cdot \beta_j + \sum_{k=1}^{K} Ln(z_{ik}) \cdot \gamma_k + \varepsilon_i \quad (2)$$

where x_{ij} are the values of the discrete variables j, and z_{ik} the values of the continuous variables k. The interpretation of the coefficients β_j or γ_k is different depending on the nature of the variable.

For continuous characteristics (introduced in the model with the logarithm), for example the size of the property, the coefficient γ_k of the variable k is the sale price elasticity with respect to this characteristic. A 1% increase of the value z_{ik} thus leads to a change (in percentage) of the sale price P_i which is directly equal to the coefficient γ_k of this variable.

For binary variable, the interpretation of the coefficient β_j is different. For these variables, some clusters have to be defined and a reference situation also has to be set. For example, noise contours have to be calculated in order to form successive classes and a special area has to be defined as a reference. In the model (Eq. (2)) x_{ij} is coded 1 if the house is located in the right area, whereas this variable is coded 0 if it is not located in this area. The goods that are in the reference area are simply not coded. The coefficient β_j cannot be interpreted as such. A "d_j" coefficient, corresponding to the impact of this variable j on the dependent variable P_i, can be calculated in each cluster with the following equation (Eq. (3)):

$$d_j = 100 \times (e^{\beta_j} - 1) \quad (3)$$

If negative, this d_j coefficient corresponds to the depreciation as a percentage of the price of a property compared to the same property if it had been located in the reference area.

In this study about the aircraft noise variable, the area whose noise level DENL is under 50 dB is chosen as the reference (see Section 3.2). More generally for the dummy variables, the reference corresponds to the largest category.

3. Selection of data

For CDG airport, two departments are submitted to aircraft noise: the Seine-et-Marne and the Val-d'Oise departments. For this study, only data from the Val-d'Oise department was available. A radius of 35 km from the airport was chosen to limit the studied area. It covers 724 km^2 (112 cities) and gathers 1,016,490 inhabitants. About half of the population lives in single family houses and the other half lives in apartments. More than half of the population (58%) own their property [27]. Two distinct hedonic price models, one for single family houses and one for apartments, have been calculated as suggested by several researchers [28–31] in order to respect the market segmentation.

3.1. Data on real estate transactions

The data on real estate transactions in the Val d'Oise department was provided by a notarial database (*Base d'information Economique Notariales – BIEN*). It records all the transactions of single family homes and apartments that occurred between 2002 and 2008 (except 2007). Inappropriate transactions such as public estate were removed. Eventually, two samples of 19,891 single family houses and 23,264 apartments were analyzed. The geographic coordinates x and y of each transaction were matched with the aircraft noise data and with further neighborhood, accessibility and environmental amenity characteristics. In order to take into account the possible inflation or the possible change in real estate market during the studied period, 5 dummy variables (one for each year) were created, and the year 2006 was chosen for single houses as the reference because it corresponds to the year when the number of transactions was the highest (respectively 2003 for apartments).

3.2. Data on aircraft noise

In order to reveal the non-linear relationship between price depreciation and noise, the hedonic price literature proposes to use noise as a dummy explanatory variable. The majority of recent studies have adopted this approach but most studies use a dummy variable with differences of 5 or 10 dB.

In this study, collaboration with the acoustic laboratory of Paris Airport (*Aéroprot De Paris – ADP*) made it possible to use the Sound Environment Curves (*Courbes d'Environnement Sonore – CES*) which provide DENL contours with a step of one dB(A) from the 50 dB contour to the 70 dB one (Fig. 1). They are calculated each year with the same INM (Integrated Noise Model) software as the PEB. The advantages of the CES with respect to the PEB are:

- They are calculated on actual annual aircraft movements which permit to take into account a possible change in noise contours over time (the PEB does not reflect the current situation, but the estimated development of air activity, infrastructure expansion and evolution of air traffic procedures in the next 10–15 years).
- The dummy variable can be more precise with clusters of a 1-dB difference instead of a 5-dB difference or more with the PEB. This will be an advantage to calculate the proposed indicator RETL (see Section 4.2) with a minimum error rate.

The choice of a noise threshold is also an important issue. For aircraft noise, and as many European countries, the French government recommends the DENL baseline contour of 55 dB [32]. However, exposure response functions for transportation noise show that people are annoyed by noise even at lower levels [1,2] and elimination of noise annoyance may occur at about 37–40 dB [11]. Navrud [11] recommends the use of an interim cut off point of 50 dB for the economic valuation of noise.

In this study, the threshold value of LDEN = 50 dB was chosen and, based on the CES curves for each year with an increment of 1 dB, 15 noise areas were used to create 14 dummy noise variables, plus one as the reference area. The reference area (LDEN < 50 dB) is a zone outside the 50 dB contour and within a buffer zone of 35 km radius around CDG airport in the Val d'Oise department. All the 15 clusters ([DENL < 50[,[50–51[,…,[61–62[,[62–63[,[DENL ⩾ 63]) were generated. The last cluster [DENL ⩾ 63] gathers all the transactions that are located outside this contour. Indeed, above 63 dB the number of transactions (89 for single houses and 174 for apartments) is too small to create specific clusters.

3.3. Land transportation noise characteristics

In order to take into account the presence of other traffic noise, two binary variables measuring the road traffic noise and the railway traffic noise were included in the hedonic models. Note that in contrast with aircraft noise, a unique threshold of L_{DEN} = 55 dB was used for the road noise and train noise variables. Consequently, only two clusters were created for each land transportation noise. They were provided by the strategic noise map of the Val d'Oise department in 2008, in accordance with the guidelines of the 2002/409/EC Directive.

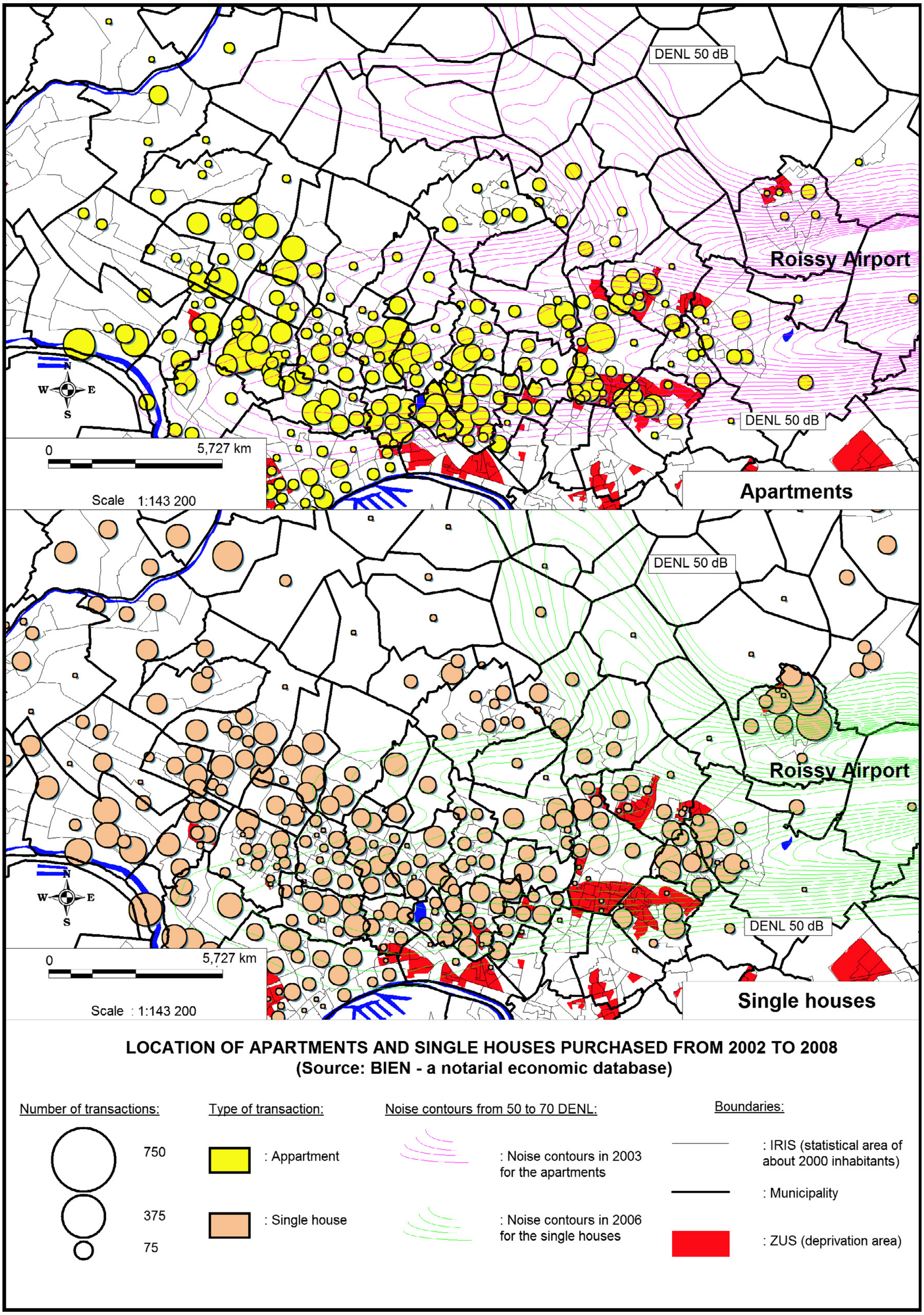

Fig. 1. Location of single house and apartment transactions between 2002 and 2008 with DENL contours for the reference year (2006 for houses and 2003 for apartments).

3.4. Other characteristics

Structural characteristics came from the BIEN database with the key features of each property: size, number of rooms, building age, number of garages, etc. Except the size variables (ground surface including the garden and living area for houses, only living area for apartments), all the numerical variables were included as dummy ones (Tables 1 and 2). Socio-demographic variables often

Table 1
List of dummy characteristics with reference clusters for single houses (all clusters are presented in Appendix A, except the IRIS clusters).

Characteristics	Reference cluster	Number of additional clusters
Year of transaction	2006	5
Month of transaction	July	11
Building age	Built between 1914–1947	6
Number of bathrooms	1 bathroom	2
Number of garages	1 garage	3
Number of floors	2 floors	3
Garden	No garden	1
Swimming pool	No swimming pool	1
Deprivation area	Outside any deprivation area	2
IRIS	La Frette sur Seine, average price = 253,394 €	259
Traffic noise	<DENL 55 dB	1
Railway noise	<DENL 55 dB	1
Aircraft noise	<DENL 50 dB	14

Table 2
List of dummy characteristics with reference clusters for apartments (all clusters are presented in Appendix B, except the IRIS clusters).

Characteristics	Reference cluster	Number of additional clusters
Year of transaction	2003	5
Month of transaction	July	11
Building age	Built between 1948–1969	5
Number of bathrooms	1 bathroom	2
Number of garages	1 garage	3
Floor of the apartment	2nd floor	3
Garden	No garden	1
Balcony	No balcony	1
Deprivation area	Outside any deprivation area	2
IRIS	Le Val d'Herblay, average price = 110,526 €	281
Traffic noise	<DENL 55 dB	1
Railway noise	<DENL 55 dB	1
Aircraft noise	<DENL 50 dB	14

include variables describing the school quality, the average or median income and variables describing the socio-professional structure (percentage of managers, employees and workers) in the neighborhood [33]. In this study, two socio-demographic dummy variables were included: ZUS_1 if the transaction is located within a Social Deprivation Area (*Zones Urbaines Sensibles – ZUS*) and ZUS_2 if the transaction is located within a 750 m radius around a ZUS. Actually, it is expected that the "*bad reputation*" of ZUS in the neighborhood weights negatively on housing prices [34]. As already mentioned in Section 2.2 and when it is not specifically developed, the reference cluster for the dummy variables corresponds to the category where the number of transactions is the largest.

In this study, some accessibility characteristics were calculated: the Euclidian distances from CDG and from a smaller airport, Le Bourget. They correspond to the distance between each housing unit and the main entrance of each airport terminal. In addition, Euclidian distances from Paris and La Défense were also calculated. However, these variables are correlated (statistically significant at the 0.01 level) with aircraft noise levels. In order to avoid linearity between variables, these distance variables were not included in the hedonic models. Another way of capturing the effect of proximity to an airport or a city is to take into account the spatial pattern of housing through IRIS (Aggregated Units for Statistical Information – *Ilots Regroupés pour l'Information Statistique*). IRIS is a homogeneous block which generally has a population of between 1800 and 5000 inhabitants (INSEE) [35]. Dummy variables were constructed for each IRIS where ten or more transactions occurred. Then 259 dummy variables were created for houses (respectively 281 for apartments). The IRIS whose median price equals the average price of the entire sample is chosen as a reference.

4. Results

4.1. Coefficients of the regression for single houses

For this paper, single family house analysis is detailed, but results concerning noise for apartments are presented in Section 4.2 in order to discuss about possible differences between the two markets. Using a log–log transformation with 2 continuous variables (the surface of the house and the ground surface) and 13 dummy characteristics (total of 50 dummy variables plus 259 IRIS variables – see Table 1), Generalised Least Squares (GLS) regression was carried out. The GLS model is able to estimate the price of single family houses with a good adjustment (R^2adj = 0.74). A hypothesis of spatial autocorrelation was rejected with the Moran Test provided in the Space Stat software, considering a weight matrix based on a 500 m distance matrix ($I = 0.01$; $p = 0.074$).

Since the focus of this paper lies on noise impact, only a brief discussion on control variables is given. All the structural characteristics influence single family house prices as expected. The annual dummy variables are negative for the years 2002–2005 and positive for the year 2008. The coefficients logically increase, meaning that property transaction prices were lower in 2002, 2003, 2004 or 2005 than in 2006, and higher in 2008. The Appendix A presents the coefficients of all the variables for single house price, with the GLS model.

IRIS dummy variables also positively or negatively influence the prices (see Fig. 2). It shows that generally the closer the property, the higher the price. This reveals that the airport proximity brings some economic advantages. Nevertheless, it is not true anymore for transactions whose locations are next to a social deprivation neighborhood (ZUS). The over or under rating prices compared to the reference cluster are similar even greater than the depreciations due to aircraft noise (Table 3).

Aircraft noise statistically has a significant and negative effect on the single family house market, as soon as $L_{DEN} > 50$ dB, and the louder the noise, the greater the effect. The aircraft noise coefficients β are transformed into depreciation values d with Eq. (3) (Table 3). These results confirm that the relationship between property value and aircraft noise levels is not linear as expected.

For single family houses, road noise statistically has a significantly negative effect on house prices (while for apartments, the railway noise is positively significant), but these variables have a lower impact compared to aircraft noise (β road = −0.015 for houses; β railway = 0.031 for apartments).

4.2. Impact of noise for apartments

Using a log–log transformation with only one continuous variables (the surface of the apartment) and 13 dummy characteristics (total of 49 dummy variables plus 281 IRIS variables – see Table 2), the GLS model is able to estimate the price of apartments with a good adjustment (R^2adj = 0.85). A hypothesis of spatial autocorrelation was rejected with the Moran Test provided in the Space Stat software, considering a weight matrix based on a 500 m distance

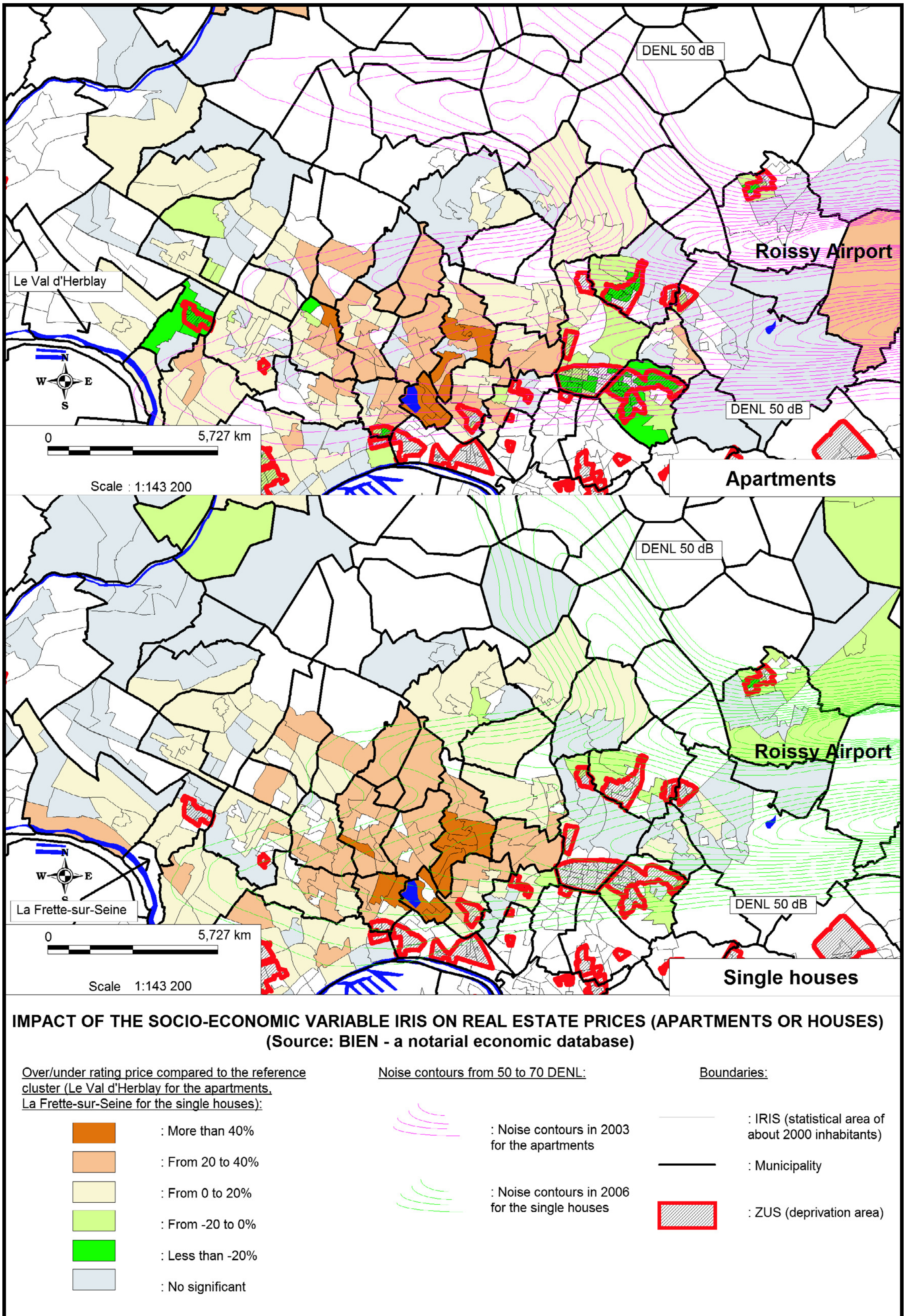

Fig. 2. Impact of the variable IRIS on house and apartment prices.

matrix ($I = 0.04$, $p = 0.062$). The Appendix B presents the coefficients of all the variables for apartment price, with the GLS model. The results concerning the impact of noise on apartment prices are presented in Table 4.

Table 3
Depreciation in percentage for single family house price related to aircraft noise.

Aircraft noise clusters based on DENL values of CES	β	Depreciation d (Eq. (3)) (%)
[50–51[	−0.018	−1.81
[51–52[	−0.017	−1.71
[52–53[	−0.025	−2.47
[53–54[	−0.025	−2.50
[54–55[	−0.025	−2.48
[55–56[	−0.064	−6.20
[56–57[	−0.097	−9.23
[57–58[	−0.116	−10.98
[58–59[	−0.110	−10.42
[59–60[	−0.121	−11.40
[60–61[	−0.128	−12.05
[61–62[	−0.144	−13.40
[62–63[	−0.174	−15.94
DENL ⩾ 63	−0.203	−18.40

Table 4
Depreciation in percentage for apartment price related to aircraft noise.

Aircraft noise clusters based on DENL values of CES	β	Depreciation d (Eq. (3)) (%)
[50–51[	−0.029	−2.86
[51–52[	−0.059	−5.74
[52–53[	−0.036	−3.53
[53–54[	−0.071	−6.90
[54–55[	−0.073	−7.06
[55–56[	−0.078	−7.55
[56–57[	−0.074	−7.09
[57–58[	−0.139	−12.94
[58–59[	−0.135	−12.59
[59–60[	−0.112	−10.60
[60–61[	−0.113	−10.73
[61–62[	−0.143	−13.35
[62–63[	−0.168	−15.45
DENL ⩾ 63	−0.125	−11.75

4.3. The Real Estate Tolerance Level (RETL)

As presented in the introduction, the idea is to model the percentage of price depreciation with the same mathematical model as that used by Fidell et al. [7] to calculate the Community Noise Level (CTL). The CTL is defined as a DENL value (or DNL) for which half of the people in a community are "highly annoyed" by aircraft noise. The CTL characterizes community reactions to transportation noise exposure.

Instead of using social survey findings about the prevalence of aircraft noise annoyance, the percentage of property value depreciation d_i (Tables 3 or 4) was taken as the input in the model. In other words, we suppose that the percentage of property value depreciation is an indirect way to characterize the prevalence of annoyance due to aircraft noise. RETL value is computed with the following steps:

(1) Compute the "effective loudness function" by converting all the DENL values into an estimated noise dose, m_i, calculated as:

$$m_i = \left(10^{\frac{L_{DEN_i}}{10}}\right)^{0.3} \tag{4}$$

(2) Compute the community specific constant A, which is the non-acoustic decision criterion. A is found by minimizing the least square difference RMSE between the percentage of property value depreciation predicted by the exponential function $e^{\frac{-A}{m_i}}$ and the percentage calculated from the regression d_i.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(d_i - e^{-\left(\frac{A}{m_i}\right)}\right)^2}{n}} \text{ is minimized} \tag{5}$$

d_i is the percentage of property value depreciation, and $e^{\frac{-A}{m_i}}$ is the exponential function which is supposed to model the percentage of depreciation.

(3) Finally, the value of RETL is the DENL value at which the property depreciation reaches 50% of the same property which would be located in the reference cluster (in this study $L_{DEN} < 50$ dB). Then $e^{\frac{-A}{m}} = 0.5$ so $A = -m \times Ln(0.5)$ and $A = \left(10^{\frac{L_{RET}}{10}}\right)^{0.3} \times 0.693$. This last equation is transformed with the logarithm $L_{RET} = \frac{\log_{10}A - \log_{10}(0.693)}{0.03}$. The RETL is then calculated with the parameter A following Eq. (6):

$$L_{RET} = 5.31 + 33.33\log_{10}A \tag{6}$$

Following the previous steps, a RETL value of 75.8 dB is obtained for both single family houses and apartments ($A = 130$) with a very good squared correlation between the calculated and the predicted depreciation values for house transaction $r^2 = 0.94$ (less good for

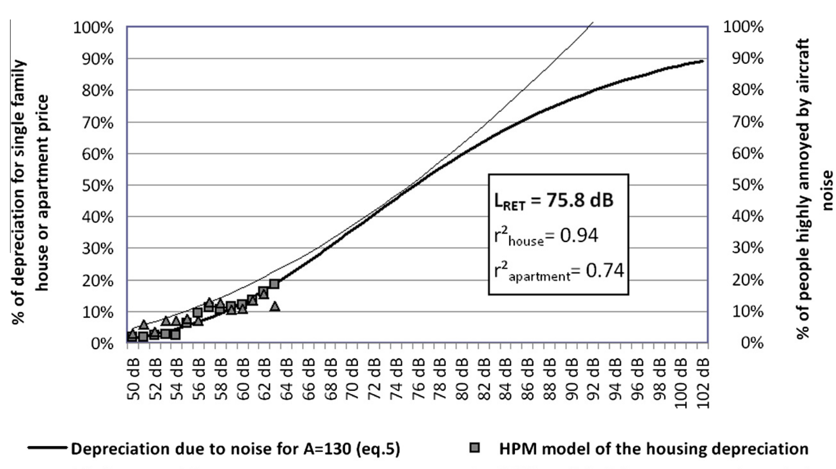

Fig. 3. Superposition of the Miedema curve and the optimized effective loudness function (for $A = 130$) compared to property depreciations calculated with hedonic price models.

apartments with $r^2 = 0.74$) in the Val d'Oise community around CDG airport.

5. Discussion

The RETL is the same for single houses and for apartments, showing that the effect of noise is similar for both markets. For houses, the depreciation increases continuously with the noise level but for apartments this effect seems to have a kind of limitation for high value of noise. This could be due to the fact that apartments could be more insulated than houses, especially near the airport. This could be due also to the type of buyers that are different for apartments compared to family houses. Further researches should bring answers to this open issue. It could be anyway interesting to collect data about the insulation of the constructions, data that are missing in this study.

It is interesting to compare the values of RETL and the values of CTL for the same community. Although there are currently some field studies around CDG Airport [36], the annoyance data is not yet available. It is then only possible to compare RETL to already published data in the Fidell paper [7]. Fidell et al. found a CTL value of 79.6 dB for a French survey in 1970 [37] and 67.6 dB for a survey around Orly/Roissy CDG airports in 2000 [38]. They also found that the mean value of the 43 CTL they calculated is 73.3 dB, while the standard deviation is 7.0 dB. All these CTLs were calculated from DNL values so the RETL and the CTL are not comparable as such. If the link between DENL and DNL proposed by Miedema and Oudshoorn for Aircraft is applied (i.e. DENL = DNL + 0.6) [2], the mean CTL value which should have been extracted from DENL would be 73.9 dB – which is surprisingly close to the RETL. Further investigations should be carried out in order to systematically compare the RETL and the CTL values.

It is also interesting to compare the percentage of property depreciation obtained from the Hedonic Price Method (HPM) with the dosage–response relationship proposed by Miedema and Oudshoorn [2] (Fig. 3). The two models are quite similar. The hypothesis that the percentage of property price depreciation can reveal the probability of being highly annoyed has to be considered.

Another application of the RETL calculation could be the observation of the temporal trends in the impact of noise exposure. Two subsets of house data have been analyzed with the HPM gathering three years of transaction (2002, 2003 and 2004) and (2005, 2006 and 2008). The first subset gives $L_{RET} = 74.4$ dB and the second subset gives $L_{RET} = 77.0$ dB. The same tendency is observed for apartments ($L_{RET} = 73.9$ dB and the second subset gives $L_{RET} = 77.8$ dB). The duration of each period maybe is not long enough to conclude but this temporal trend should be further investigated with economical conditions, in order to follow the evolution of the impact of noise around airports.

The RETL of some specific municipalities which are spread over a large diversity of sound environments can also be calculated. Goussainville city for example, which is located very close to the runway (North-West of the airport), is characterized by a RETL value for houses of 70.4 dB, showing that the market of this community is less tolerant to noise than the global community. This over sensitivity to the aircraft industry could be explained by the same non-acoustic factors that are involved in noise annoyance, but at a community level (for example the fear of aircraft because of the Tupolev crash in 1973).

6. Conclusion

The use of a notarial database analyzed with the hedonic price model made it possible to calculate the percentage of property price depreciation around CDG airport, with 1-dB steps. A new indicator, "the RETL" (Real Estate Tolerance Level), inspired from the CTL (Community Tolerance Level) has been calculated in order to characterize the impact of noise around airports. The following conclusions can be drawn from this study:

(1) The combination of the notarial database with the GIS database makes it possible to extract the impact of different characteristics on property prices, each one independently from the others. As far as noise is concerned, the impact on the real estate market around CDG can be compared to the impact on declared annoyance. The depreciation of a property due to noise is quite similar to the mean probability for people to be highly annoyed, this mean being established over more than 40 airports for Fidell and his colleagues, and over 20 airports for Miedema and Oudshoorn.
(2) The calculation of the RETL is as easy as the calculation of the CTL with the same acoustic unit which is the dB. The link between these two indicators during a same period could be systematically tested in order to consider if the CTL can be easily predicted from the RETL.
(3) The RETL, even if different from the CTL, can be used to characterize the evolution of the impact of noise over the years. The RETL can also be used to discriminate different communities around the same airport or around different airports.

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Appendix A

GLS table for single house price except for the 259 IRIS dummy variables whose 181 are significant.

Characteristics	Variables	Coefficients "β" or "γ"	t	p-Value	Depreciation "d" in %
	(Constant)	9.513	229.64	0.00	
Area	Living area (Ln)	0.364	41.20	0.00	36.40
	Ground surface (Ln)	0.208	69.95	0.00	20.79
Year	2002	−0.505	−82.81	0.00	−39.65
	2003	−0.405	−65.22	0.00	−33.33
	2004	−0.286	−46.04	0.00	−24.86

Appendix A (*continued*)

Characteristics	Variables	Coefficients "β" or "γ"	t	p-Value	Depreciation "d" in %
	2005	−0.136	−22.84	0.00	−12.68
	2008	0.065	10.46	0.00	6.72
Month	January	−0.082	−9.90	0.00	−7.85
	February	−0.063	−7.76	0.00	−6.14
	March	−0.063	−7.77	0.00	−6.11
	April	−0.058	−6.96	0.00	−5.62
	May	−0.052	−6.35	0.00	−5.03
	June	−0.018	−2.50	0.01	−1.77
	August	0.017	2.13	0.03	1.69
	September	0.001	0.07	0.94	NS
	October	−0.007	−0.83	0.41	NS
	November	−0.004	−0.50	0.61	NS
	December	0.006	0.85	0.40	NS
Age of the construction	Unknown	−0.001	−0.16	0.87	NS
	⩽1913	0.002	0.21	0.83	NS
	1948_1969	0.017	2.03	0.04	1.71
	1970_1980	0.043	4.85	0.00	4.42
	1981_1991	0.053	5.80	0.00	5.42
	⩾1992	0.079	6.69	0.00	8.18
Bathroom	No bathroom	−0.241	−27.91	0.00	−21.40
	Nb ⩾ 2	0.128	28.99	0.00	13.62
Garage	Unknown	−0.052	−6.07	0.00	−5.07
	No garage	−0.070	−16.77	0.00	−6.78
	Nb ⩾ 2	0.049	6.13	0.00	4.99
Number of floors	Unknown	−0.094	−3.51	0.00	−8.97
	One floor	−0.133	−28.83	0.00	−12.49
	Nb ⩾ 3	0.074	13.54	0.00	7.70
Garden	One	0.053	6.30	0.00	43.90
Swimming pool	One	0.165	6.24	0.00	23.11
Deprivation area	ZUS_1	−0.084	−3.34	0.00	−8.05
	ZUS_2	−0.034	−4.77	0.00	−3.37
Traffic noise	DENL ⩾ 55	−0.015	−2.08	0.04	−1.49
Railway noise	DENL ⩾ 55	0.000	−1.45	0.15	NS
Aircraft noise	[50–51[	−0.018	−2.07	0.04	−1.81
	[51–52[	−0.017	−1.70	0.05	−1.71
	[52–53[	−0.025	−2.15	0.03	−2.47
	[53–54[	−0.025	−2.00	0.05	−2.50
	[54–55[	−0.025	−1.90	0.05	−2.48
	[55–56[	−0.064	−4.48	0.00	−6.20
	[56–57[	−0.097	−6.27	0.00	−9.23
	[57–58[	−0.116	−6.91	0.00	−10.98
	[58–59[	−0.110	−5.73	0.00	−10.42
	[59–60[	−0.121	−5.85	0.00	−11.40
	[60–61[	−0.128	−6.19	0.00	−12.05
	[61–62[	−0.144	−6.30	0.00	−13.40
	[62–63[	−0.174	−6.64	0.00	−15.94
	DENL ⩾ 63	−0.203	−6.28	0.00	−18.40

Appendix B

GLS table for apartment price except for the 281 IRIS dummy variables whose 195 are significant.

Characteristics	Variables	Coefficients "β" or "γ"	t	p-Value	Depreciation "d" in %
	(Constant)	8.377	287.40	0.00	
Area	Living area (Ln)	0.742	132.36	0.00	74.17
Year	2002	−0.120	−23.30	0.00	−11.32
	2004	0.143	27.01	0.00	15.36
	2005	0.338	63.82	0.00	40.15
	2006	0.507	95.78	0.00	66.06
	2008	0.615	107.51	0.00	84.95
Month	January	−0.087	−12.48	0.00	−8.32
	February	−0.069	−9.67	0.00	−6.66
	March	−0.067	−9.60	0.00	−6.51
	April	−0.054	−7.73	0.00	−5.29
	May	−0.047	−6.57	0.00	−4.55
	June	−0.019	−2.93	0.00	−1.90
	August	0.018	2.40	0.02	1.83
	September	0.007	1.06	0.29	NS
	October	0.003	0.36	0.72	NS
	November	0.009	1.12	0.26	NS
	December	0.027	4.01	0.00	2.76
Age of the construction	⩽1913	0.018	1.99	0.05	1.85
	1914_1947	−0.020	−2.89	0.00	−2.00
	1970_1980	0.009	2.03	0.04	0.92
	1981_1991	0.055	8.88	0.00	5.63
	⩾1992	0.111	15.72	0.00	11.77
Bathroom	No bathroom	−0.078	−10.95	0.00	−7.46
	Nb ⩾ 2	0.055	6.72	0.00	5.67
Garage	Unknown	−0.104	−10.03	0.00	−9.91
	No garage	−0.078	−19.12	0.00	−7.53
	Nb ⩾ 2	0.056	8.22	0.00	5.76
Floor of the apartment	Ground and 1st floor	0.009	2.24	0.02	0.91
	3rd floor	0.022	4.67	0.00	2.18
	Floor ⩾ 4th	0.005	1.11	0.27	NS
Balcony	One	0.047	6.49	0.00	4.80
Garden	One	0.047	6.35	0.00	4.86
Deprivation area	ZUS_1	−0.085	−4.68	0.00	−8.17
	ZUS_2	−0.048	−6.20	0.00	−4.69
Traffic noise	DENL ⩾ 55	0.000	−1.01	0.20	NS
Railway noise	DENL ⩾ 55	0.031	2.18	0.03	3.15
Aircraft noise	[50–51[	−0.029	−3.19	0.00	−2.86
	[51–52[	−0.059	−5.17	0.00	−5.74
	[52–53[	−0.036	−2.61	0.01	−3.53
	[53–54[	−0.071	−4.70	0.00	−6.90
	[54–55[	−0.073	−4.49	0.00	−7.06
	[55–56[	−0.078	−4.53	0.00	−7.55
	[56–57[	−0.074	−3.96	0.00	−7.09
	[57–58[	−0.139	−6.68	0.00	−12.94
	[58–59[	−0.135	−6.23	0.00	−12.59
	[59–60[	−0.112	−4.52	0.00	−10.60
	[60–61[	−0.113	−3.49	0.00	−10.73
	[61–62[	−0.143	−3.74	0.00	−13.35
	[62–63[	−0.168	−3.62	0.00	−15.45
	DENL ⩾ 63	−0.125	−2.51	0.01	−11.75

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