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Feel it or Measure it.
Perceived vs. Measured Noise in Hedonic Models

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Summary

The aim of this paper is to compare the use of scientific and perceived noise measures in a hedonic model framework. Although in theory the use of subjective variables is recommended, most of the empirical applications use scientific noise variables. Using three different databases, we are able to obtain a relative large sample of about 2 800 apartments located in Geneva, Switzerland. The sample contains both scientific measures and perceived noise data, as well as structural and accessibility variables. However, in order to compare scientific and perceived noise measures we need them expressed in comparable units, e.g. dB(A). Since no such data is available, we refer to the acoustic literature to transform a categorical variable on perceived external noise into a measure directly comparable to a scientific measure of noise in dB(A). We show that a clear relationship appears between the scientific measure of road traffic noise and the transformation of the perceived external noise in dB(A). From this relationship, it is interesting to note that: 1) There is a great variability in the perception of noise when the scientific noise level is relatively low; and 2) The systematic bias of subjective overestimation of low probability events that has been highlighted in the risk literature also parallels with our findings here concerning the perceived exposure to external noise. Having both noise measures in comparable units, we are able to analyse their performance in the context of the hedonic model. We conclude that for moderate to high noise levels, the scientific measures of noise safely approximate the individual perception of it. This last result is very promising from a policy-making point of view, for which the use of scientific measures are more convenient and transferable than subjective perceptions.

JEL classification

Q5, Q51, D61, R31

Keywords

Noise, measured noise, perceived noise, housing market, hedonic model, hedonic approach, external cost, monetary valuation, geographical information system (GIS)

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1. Introduction

This paper examines whether perceived or measured noise should be used in hedonic models. The use of the hedonic model to assess the economic value of an environmental good has been popularised thanks to the seminal work of Rosen (1974). Indeed, Rosen provided the theoretical foundation of the property-hedonic model, by assuming that heterogeneous goods are valued for their utility-bearing characteristics. Therefore, by using the hedonic approach, the implicit prices of the house attributes can be revealed from the observed prices of differentiated products and the quantities of characteristics associated with them. Given the key assumption that the housing market is competitive (see Freeman, 1993), the equilibrium hedonic price schedule reflects the locus of tangencies between the households' utility functions and landlords' cost functions. Hence, at the equilibrium, the rent P is determined by the implicit price of the dwelling's characteristics, z, $P = P(z)$, which is the general form of the hedonic price model (see e.g. Palmquist, 1999). The characteristics are often decomposed in a vector of structural (for example the number of rooms), accessibility (for example proximity to public transportation), neighbourhood (for example proportion of green areas) and environmental quality (for example noise) variables. Hence, even if there is a missing market for environmental quality (such as quietness), by unbundling the housing product it is possible to assess the (implicit) value that individuals are revealing by their (explicit) choice in the housing market.

Of course, some property characteristics, such as the number of rooms or the presence of an elevator in the building, are variables that are easily observable and thus there are no differences between their measure and households' subjective perception of them. However, other housing characteristics are not directly quantifiable and are subject to individual perception, which in turn can vary quite substantially across individuals, depending for instance on their personal qualities or their culture. Housing characteristics such as "a good view" or "a quiet area" will typically be determined by subjective assessments. For such characteristics, the question thus arises of which measure, subjective perceptions or scientific measures, should be used in order to quantify such characteristics. As highlighted by Palmquist (2005), if property values are to be affected by an environmental amenity such as noise, this latter has to be perceived by the residents. In other words, the measure of noise which is needed in hedonic studies should be related to individual preferences or, more precisely, it should be a measure of noise which influences the individual when choosing an apartment and paying the rent. The same argument is exposed by Viscusi (1978), in the context of the hedonic approach to estimate the wage premium workers receive for job risk exposure. Viscusi stated that ideally, the measure of risk reflecting the workers' and the firms' subjective assessments of the job risks should be used, rather than the less perfect scientific measures, extracted from national datasets, often preferred in practice.

However, even if researchers claim that the economic value of environmental goods should be based on subjective perception rather than on a scientific measure of it, only relatively few hedonic models using perceived quality data can be found in the literature. At least two explanations can be given to this preference for the scientific measures. Firstly, collecting perceived data from individuals is highly time-consuming and costly. Secondly, from a policy-making perspective, the use of scientific measures is more convenient and transferable than that of the subjective perceptions. In this context, it should be noted that several countries, e.g. the USA, EU and Switzerland, require some kind of formal or informal cost-benefit analysis to implement public policies particularly for major infrastructure (see e.g. US OMB, 1996; EC, 1999; OFEFP, 1998). Moreover, in the legal context (e.g. monetary compensations to individuals who suffer from noise disturbances), both legislative noise limits and economic assessment of noise are usually made with respect to its scientific measure, e.g. decibels[1].

Given that most of the empirical hedonic studies are based on the scientific measures of environmental quality, it is essential to test whether those measures of the environmental good are reliable instruments for subjective perceptions. Unfortunately, in the literature we are unaware of studies analysing this question, in particular in relation to noise.

In this paper, by merging two different datasets and by adding GIS data, we obtain a relatively large sample of about 2 800 apartments located in the Canton of Geneva, Switzerland, which contains detailed apartment characteristics, as well as subjective and scientific noise measures. Our focus on Geneva is dictated by several reasons, in particular because it possesses a large rental market, it has both a highway and an airport near the city and we can access several rich databases, including GIS data. In Section 2, after discussing how scientific and perceived variables have been treated in the hedonic literature, we show how we made the perceived noise measure comparable to the scientific one, using an approach proposed in the acoustic literature. After describing the dataset in Section 3, we are then able to compare, in Section 4, different hedonic equations using subjective or scientific data and to assess the relative performance of those measures in explaining rent differentials. Section 5 concludes.

2. Making Scientific and Perceived Noise Measures Comparable

The literature on whether perceived or measured variables should be used in hedonic models, particularly in relation with noise, is relatively silent. The paper that most directly analyse the consistency of using scientific measures instead of subjective perception in a hedonic model is Poor, Boyle, Taylor and Bouchard (2001), but it relates to water quality. The authors concentrate on water clarity and they used secchi disk measurements as scientific measures: the depth at which the disk disappears from sight is recorded as the measure of clarity. For the subjective measure, through a survey respondents were asked to rate in feet the minimum water clarity of a lake. In this case, scientific and subjective measures are thus expressed in the same units. The correlation coefficients between the subjective and scientific measures range from 0.33 to 0.65 for the different lakes studied. Interestingly, they find that the subjective measures of water clarity tend to be systematically lower than the scientific measures. They argue that it might arise from the fact that individuals are untrained to produce such measures of water clarity. By estimating two non-nested hedonic equations, one using the perceived measures and the other using a scientific measure, the authors are able to test the predicting power of the two measures using a Davidson-MacKinnon J-test. They found that the scientific measure better reflect the amenity levels considered by the property owners at the time of the purchase. In the same domain, Epp and Al-Ani (1979) fitted two hedonic property models to assess the economic value of

[1] For instance, the Swiss Federal Administration proposes a rule-of-thumb of 1 per cent per dB(A) to evaluate the economic efficiency of noise-reduction projects and measures (OFEFP, 1998).

water quality of rivers and streams in Pennsylvania. One model uses a scientific measure of water acidity using the water pH value, while the other applies a perceived water quality measure obtained from a survey. They found that water quality has a significant impact on the price both using scientific or perceived measures. However, they could not conduct any tests to compare the two variables, since the scientific and the subjective measures are not reported in comparable units.

In a slightly different context, Lang and Jones (1979) compared the visual attractiveness, neighbourhood prestige, school quality and accessibility of fourteen different neighbourhoods within a US Midwestern city. Subjective measurements were obtained through a survey of home-owners, while the scientific proxy measures were the median neighbourhood income and median education, and neighbourhood distance from the central business district. Nested model tests were performed to assess the degree to which one type of measure provides additional predictive power not incorporated by the other amenity measure. The authors found that the price prediction performance of the model incorporating only proxy measures is essentially the same as the model that incorporates both subjective measure and scientific proxies. A similar question was investigated by Chattopadhyay, Braden and Patunru (2004), who combined survey data on homeowners' perceptions of the safety of Waukegan Harbour with market transactions data to investigate how perceptions guide actual market behaviour. They modelled the impact of the proximity of the harbour using three variables: a scientific measure of distance between the property and the harbour and two subjective measures from a survey on the safety and attractiveness of the harbour. They found that the scientific measure of distance was highly significant with the expected sign, while the perception indicators of the harbour disamenity were not significant. However, since the scientific measure could capture a significant amount of the negative effects linked to the harbour proximity, they tested whether the distance embodied the perceived effects by disentangling the perceived disamenity from the scientific distance measure. The results of this new estimation show that the distance was still highly significant and that, unlike in the previous estimation, the coefficients on the perceived variables became significant. This finding shows that homeowners who perceived the disamenity tended to locate at a higher distance from the harbour and that once perceived effects were disentangled, their effects became non negligible.

On the specific subject of noise, we are not aware of studies comparing subjective and scientific measures. Heuristic empirical comparisons of the results from the hedonic model (often using scientific data) and stated preference techniques, in which survey data (i.e. subjective perceived data) are used to monetarily assess the noise impacts, showed that results can be similar or different, without any systematic analysis for the reasons (see Bjorner, 2004; Navrud, 2002; Adamowicz, Swait, Boxall, Louviere and Williams (1997). Of course, in the literature there are a number of surveys on the impact of noise on housing prices using the hedonic approach, which demonstrates a wide range of estimations. For instance, a review of 22 studies on noise from road traffic showed that the results ranged from 0.08 per cent to 2.22 per cent per decibel, respectively from 0.06 per cent to 2.30 per cent for aircraft noise (see Hawkins, 1999; Bateman, Day, Lake and Lovett (2001). Those differences can be explained by the large differences in the empirical approaches, contexts, data, periods, as well as the scientific measures of noise which are used. Although Nelson (2004) mentioned that the scientific noise measure could be a source of difference in the results, he did not explore further this question in the meta-analysis of twenty USA and Canadian studies. Baranzini and Ramirez (2005) is to our knowledge the only study that systematically tested different scientific noise measures in order to assess whether the impact of noise depends on its measure. They found that the economic impact of road traffic noise in the Geneva rental market did not depend on the scientific noise measure and that for each additional decibel the rent decreased by about 0.25 per cent in average. As for the impact of aircraft noise, they showed that the scientific noise measure which better relates to annoyance had a higher impact on rents.

From the above, we can thus conclude that, to our knowing, a direct comparison of subjective and scientific noise measures using the same economic valuation technique has not been studied to date. One of the main difficulties for such an exercise is related to the fact that scientific noise data and subjective measures are generally not directly comparable, since in particular the scientific noise measure is hardly understandable by individuals. Therefore, in the literature we can typically find hedonic models using categorical variables to assess the impact of noise on rent, in which individuals judge if they are exposed to “low”, “high” or other categories of noise, and hedonic models assessing the impact of noise in decibels.

In the remaining part of this section, we present the most commonly used scientific noise measures, our perceived noise variables and the methodology we used to make our noise measures comparable.

2.1 Scientific noise measures

Most of the literature on the impact of noise on housing prices has generally used one (occasionally two) measure of noise, mostly because of data availability and in order to avoid multicolinearity problems. Bateman et al. (2001) argue that it is difficult to find a measure of noise that truly reflects the impact of noise on households. They note that the consequences of noise pollution can range from physiological to pathological and to psychological disorders in individuals. Noise annoyance is quite complex since it does not simply arise from the noise magnitude, but also from its intensity, frequency, duration, variability and time of occurrence during day and night. Moreover, traffic noise annoyance also depends on the traffic characteristics, i.e. type of vehicles, street flooring, etc. Consequently, Bateman et al. (2001) claim that there is no “correct” way to measure noise, and that in practice, starting from the scientific measure, different indices have been constructed in order to better take account of annoyance, although the choice of the scientific measure itself is often constrained by data availability. For instance, Nelson (1982) supposed a semi-logarithmic relationship between the annoyance (*E*) and a scientific measure of traffic noise (*L*), so that $E = \delta_0 e^{\delta_1 L} \varepsilon_1$. Then, by choosing an exponential functional form for the hedonic equation, such as $P = \alpha_0 S^{\alpha_1} A^{\alpha_2} N^{\alpha_3} E^{\alpha_4} \varepsilon_2$, in which *P* stands for the rents or property prices, *S* for structural characteristics, *A* for accessibility, and *N* for neighbourhood characteristics, by taking the logarithm and substituting *E* in *P*, it leads to $\ln P = \beta_0 + \beta_1 \ln S + \beta_2 \ln A + \beta_3 \ln N + \beta_4 L + \varepsilon_3$. Hence, while this expression introduces a scientific measure of noise in the relationship, it could account for the subjective annoyance.

The scientific indexes of noise that have been most frequently used in hedonic property studies are expressed in the A-weighted decibel scale (dB(A)) to better approximate the noise perceived by the human ear. These are (Nelson, 1982):

(i) The equivalent continuous noise level (L_{eq}), which represents the energy mean of the noise level averaged over the measurement period, with the daytime noise level, averaged noise level over 15 hours, and the night-time noise level, averaged noise level over 9 hours, being the most popular L_{eq} measures. Swiss noise regulation stipulates that the road traffic noise in residential area should not exceed 60 dB(A) during the day and 50dB(A) during the night (see Swiss Noise Abatement Ordinance, art. 43);

(ii) The day-night noise index (L_{dn}), which attempts to better reflect the fact that noise is more annoying at night by penalizing night noise;

(iii) The day-evening-night noise index (L_{den}), which is another index, related to L_{dn}, that also tries to better account for annoyance by introduction a correction of 5 dB(A) for evening noise and a 10 dB(A) correction for night-time noise. The L_{den} index is the uniform noise metric used by European Union (EU Directive, 2002);

(iv) The peak noise (L_{10}), the medium noise (L_{50}) and the background noise (L_{90}) measures, which, reflect the distribution of noise over the day by measuring the noise level that is exceeded 10 per cent, 50 per cent and 90 per cent of the time respectively;

(v) The noise pollution level (NPL), which accounts for the variability in the noise pollution;

(vi) The noise dynamics ($L_{10} – L_{90}$), which represents the difference between the peak value and the background noise, since noises with large variations in level are generally perceived as more intrusive.

From the Geneva Cantonal Office for Protection against noise, we obtained the yearly averaged daily (Lr_D) and night (Lr_N) traffic noise levels in dB(A) units measured at the most exposed façade of the buildings. Using these data, we can calculate the day-night road traffic noise index according to the following formula:

$$L_{dn} = 10\log[10^{Lr_D/10}(15/24) + 10^{(Lr_N+10)/10}(9/24)] \quad (1)$$

In the acoustic literature, the L_{dn} is often used since it better accounts for the higher annoyance of noise during the night. The noise levels in our sample are briefly described in Table 1.

The mean exposure to daily road traffic noise (Lr_D) is 65 dB(A), a value slightly smaller than the day-night road traffic noise index (L_{dn}). Interestingly, only about 8 per cent of the apartments in our sample are exposed to a noise level lower than 55 dB(A), which corresponds to the planning regulations for housing areas in Swiss law (see Swiss Noise Abatement Ordinance, art. 43). Similarly, only about 27 per cent of the apartments are exposed to a noise level that is below the legal limit of 60 dB(A) and about 8 per cent are exposed to a noise level that equals or exceeds the alert limit of 70 dB(A). Very similar results are obtained for the day-night noise index. However, note that these values refer to the noise exposure of the building itself and do not account for potential phonic isolation, such as double-glazing windows, that can substantially reduce the noise exposure of the dwelling. Moreover, for policy-making reasons, noise is often measured for those buildings expected to be exposed to high traffic noise, which implies that 65 dB(A) is not representative of the average noise level in the Geneva Canton.

Table 1 : Descriptive statistics of the noise variables (n = 2 794)

Daytime noise level (Lr_D) in dB(A)			
Sample mean = 65	Freq.	Percent	Cum.
$45 \geq Lr_D < 50$	43	1.54	1.54
$50 \geq Lr_D < 55$	176	6.30	7.84
$55 \geq Lr_D < 60$	523	18.72	26.56
$60 \geq Lr_D < 65$	926	33.14	59.70
$65 \geq Lr_D < 70$	896	32.07	91.77
$Lr_D \geq 70$	230	8.23	100.00
Day-night noise index (L_{dn}) in dB(A)			
Sample mean = 66	Freq.	Percent	Cum.
$45 \geq L_{dn} < 50$	42	1.50	1.50
$50 \geq L_{dn} < 55$	166	5.94	7.44
$55 \geq L_{dn} < 60$	468	16.75	24.19
$60 \geq L_{dn} < 65$	877	31.39	55.58
$65 \geq L_{dn} < 70$	882	31.57	87.15
$L_{dn} \geq 70$	359	12.85	100.00
Perceived external noise			
Sample mean = 3.25	Freq.	Percent	Cum.
No external noise (rate 1)	76	2.72	2.72
Little noise (rate 2)	588	21.05	23.77
Moderate noise (rate 3)	1 010	36.15	59.91
Important noise (rate 4	692	24.77	84.68
Very important noise (rate 5)	397	14.21	98.89
No answers	31	1.11	100.00

2.2 Perception of noise

Of course, in order to be able to compare the scientific and the subjective measures, we should have the data in comparable units. A perceived noise assessment that would be directly comparable to our scientific measures would result from a survey question, such as: “To what decibel level of traffic road noise do you feel your dwelling is exposed to ?”. Classes of decibels or pure decibel level could be proposed as multiple choices answers to help the respondents. Unfortunately, such a survey is not available. However, we have accessed the 2003 “Statistical information survey on rent” of the Swiss Federal Statistical Office, in which the respondents have answered to a qualitative question on the external noise level to which they perceived to be exposed to. The question was the following: “How important do you rate the noise coming from outside the building on your dwelling? Null / slightly null / moderated / important / very important”.

In Table 1, those alternative responses are ranked from 1 (which corresponds to no perceived external noise) to 5 (very important external noise). From this table we can see that in our sample the mean perceived external noise is 3.25, a value that is slightly higher than the “moderate external noise” category (rate 3). As already discussed, with respect to the original survey database (18 943 observations), our sample is not representative of the average perceived noise in the Geneva canton, since in the final dataset we keep the observations for which we have both the scientific and the perceived noise measures[2].

The perceived noise measure is obviously not directly comparable to the scientific measure. Note that the simple correlation between the measured yearly averaged daily traffic noise, reported in dB(A), and the categorical variable on external noise perceived by the residents is 29 per cent. This relatively low correlation coefficient, can be explained by different factors. Firstly, as mentioned in Viscusi (1993) and Martin, Tarrero, Gonzalez and Machimbarrena (forthcoming), various specific parameters, particularly of personal, cultural or of psychological order, can influence the perception of noise. For example, for a given noise level, older people might feel more annoyed than younger ones. Secondly, this low correlation coefficient might result from the fact that the perceived noise refers to all external noises, while the measured noise only refers to the road traffic noise. Therefore, an apartment near the airport but away from busy roads might be assessed as very noisy while the actual road traffic noise is low. Finally, if the respondents accounted for the isolation of their dwellings against external noise (e.g. double-glazing windows), a difference between the perceived noise and the measured noise can arise, since the level of external noise within the dwelling might be substantially reduced. By performing a simple multinomial logit model estimation (not reported here), we can confirm that the perceived external noise rate is indeed related to the age of the building and its renovation. If the building is recent or if it has been renovated, then the probability that the "no noise" category is chosen is higher than the probability to choose any other category (little, moderate, important, or very important noise).

Thanks to the acoustic literature, we are however able to develop a methodology to transform our perceived noise data into a measure that is comparable to our scientific measure. Specifically, we refer to the influential studies of Miedema and Vos (1998) and Miedema and Oudshoorn (2001), who represented the public annoyance as a function of measured transportation noise.

2.3. Transformation of the perceived noise variable

Miedema and Vos (1998) and Miedema and Oudshoorn (2001), based on the seminal work of Schultz (1978), draw exposure-response functions that show how annoyance due to environmental noise is associated with a given noise exposure level, for different transportation noise sources. More specifically, Miedema et al. (1998, 2001) performed a meta-analysis using 55 datasets derived for a total of 63 969 respondents, and were able to fit a model in which the percentage of people highly annoyed (%HA) by noise is a function of the day-night noise level (L_{dn}) and of an error term representing the variability of the annoyance reactions by noise exposure level. They built three different models, one for each source of noise (aircraft, road traffic and railway), since earlier studies have demonstrated significant differences in the exposure-response relationships for these three noise sources.

[2] We performed a probit model to estimate the selection probability of a given category of perceived noise. The estimation (not reported here) confirms that the dwellings exposed to "moderate", "important" and "very important" perceived external noise have a higher probability to be included in our sample.

In the case of road traffic noise, the curve is derived from the following polynomial approximation (Miedema et al., 1998)[3]:

$$\%HA = 0.03(L_{dn} - 42) + 0.0353(L_{dn} - 42)^2 \quad (2)$$

A simple use of this relationship would be to use our scientific measure of noise, L_{dn} , to get the percentage of people highly annoyed (%HA). Instead, what we seek is to get a subjective noise variable expressed in dB(A) to be then compared with the scientific noise measure, which is expressed in dB(A). Therefore, we will use our categorical perceived noise variable to calculate the percentage of people who feel highly annoyed and then, using (2), we will transform this %HA into a subjective-L_{dn} in decibels. This transformation involves three steps: i) On our 1 to 5 scale, determine the cut-off point that will define people who are "highly annoyed" by external noise; ii) Given this cut-off point, calculate the actual percentage of "highly annoyed" people in our sample; and iii) Transform the percentage of "highly annoyed" people (%HA) into "perceived dB(A)", by using the reverse of the polynomial function (2).

2.3.1 Determination of the annoyance cut-off point for annoyance

From which point on the categorical scale can we judge that people are "highly annoyed" by noise? Is it the people that rate the external noise to be "very important" only, or should the respondents who find the external noise to be "important" be included ? Miedema et al. (2001, p. 410) stated that "if the cut-off is 72 on a 0-100 scale, then the result is called the percentage of highly annoyed persons (%HA); with a cut-off at 50 it is the percentage "annoyed" (%A), and with a cut-off at 28 it is the percentage "(at least) a little annoyed" (%LA)."

In accordance to this literature, we will use the cut-off point at 72, which in terms of our scale from 1 to 5, corresponds at a cut-off point of 3.88 (=(72*4/100)+1). The respondents who chose a value higher then 3.88 on the categorical scale, will be defined as "highly annoyed" by external noise. More precisely, those respondents who chose the categories 1 (no noise) or 2 (little noise) will be assigned the null value, reflecting the fact that they do not belong to the group of "highly annoyed" people, since the upper boundaries of these categories are below the cut-off point. In opposition, those respondents who chose the values 4 (annoyed) and 5 (highly annoyed) will be assigned the value 1, since the lower bound of these categories are above the cut-off point. They are member of the group of the "highly annoyed persons". The category 3 (moderate noise), with 3 as lower bound and 4 as higher bound requires more attention since it encompasses the cut-off point. The value assigned to these respondents will be the probability that these individuals belong to the highly annoyed group, assuming that the annoyance score is uniformly distributed within the category. Therefore, the respondents who chose the third category will be given the value 0.12 (=(4-3.88)/(4-3)).

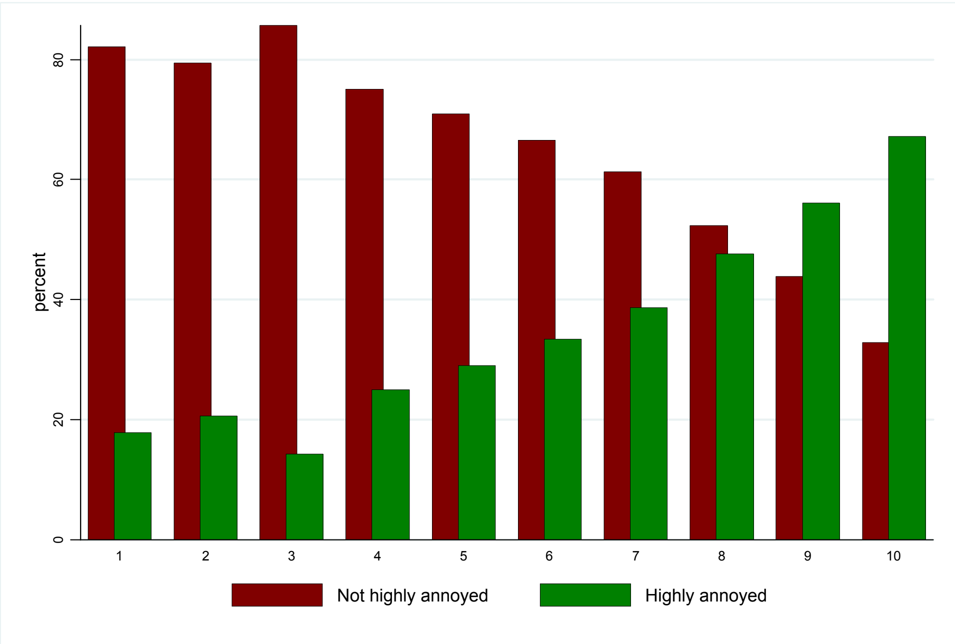
Once the cut-off point is defined, it becomes then possible to calculate the percentage of responses in our sample that exceeds the cut-off point at different effective noise levels.

[3] Note that Miedema et al. (2001) present a more accurate relationship of third-order polynomial order. For calculation reasons, we stick to their "simple" model.

2.3.2 The calculation of the percentage of highly annoyed people (%HA)

The percentage of highly annoyed people (%HA) is calculated for each measured L_{dn} level by summing up the number of answers in our sample corresponding to the category of "highly annoyed" persons, and then dividing it by the total number of responses at the given L_{dn} level. The following Figure 1 illustrates the proportion of people "highly annoyed" by class of 3 dB(A).

Figure 1: Distribution of perceived exposure to noise, by dB(A) level



As expected, when the day-night noise level increases, the percentage of highly annoyed people also increases. The respondents who feel "highly annoyed" at low scientific noise exposure levels might also be affected by other noise disturbances like aircraft or railway noise, kids, bars, etc. Similarly, the respondents who declared not to feel exposed to noise at high scientific noise levels might be protected from noise by efficient acoustic isolation of the building.

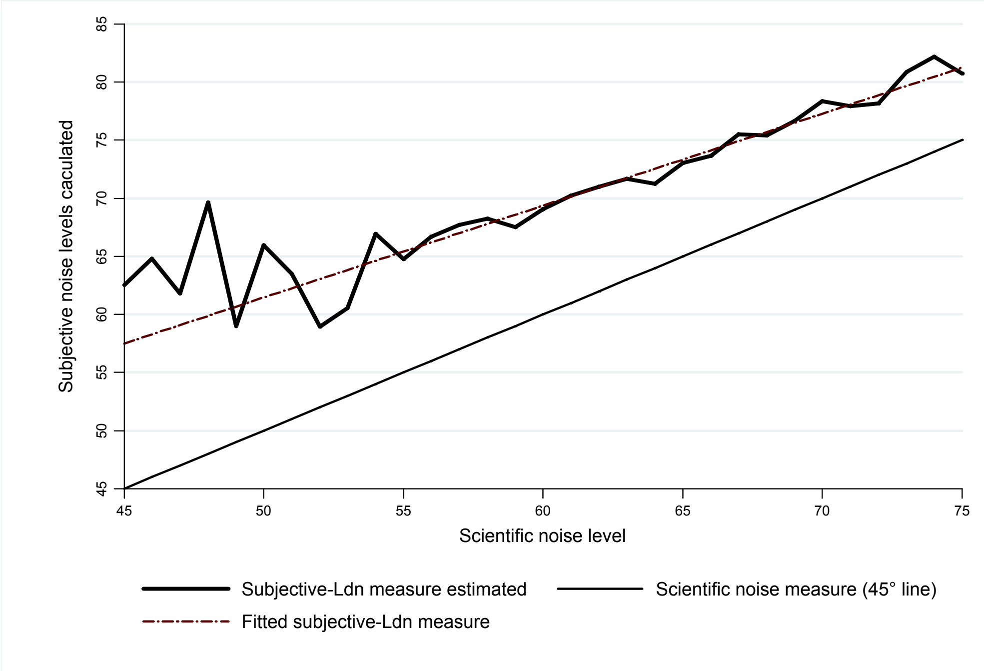
2.3.3 Transforming the %HA into dB(A) using polynomial approximations

In this section, our objective is to get a perceived measure that is directly comparable to our scientific measure expressed in dB(A). To do so, we use the reverse of expression (2) to transform the %HA, calculated in the previous sub-section with the perceived external noise data. With this procedure, we are able to calculate a "subjective-L_{dn}" noise measure expressed in dB(A) [4]. The relation between the scientific L_{dn} and our subjective-L_{dn} measures is illustrated in Figure 2.

[4] The second-order polynomial degree formula that we solve is:

$$\text{Subjective - }L_{dn}\,(dB(A)) = \left(\frac{(-0.03 + \sqrt{(0.03^2) + (4 * (\%HA) * 0.0353)}}{(2 * 0.0353)}\right) + 42$$

Figure 2: Scientific and Subjective-L_{dn} noise measures in dB(A)



A clear relationship appears in Figure 2 between the day-night traffic noise level in dB(A) estimated using the perceived values from the survey and the scientific L_{dn}. If the adapted-subjective noise levels were exactly the same as the scientific noise measure, then all the points would lie on the diagonal. We note however that the estimated values lie above the diagonal, which is not surprising since as already mentioned, our scientific measure of L_{dn} refers only to road noise, whereas the perceived noise measure is based on a survey question about "external noise" without any distinction to the source of noise. It is therefore highly possible that some other noise (from night life or from other transportation service like railway or aircrafts) comes in addition to the pure road traffic noise in the subjective measure.

From Figure 2, we can highlight two interesting findings:

1. For low values of L_{dn}, there is a lot of variability in the perception of noise. This result is in accordance with the acoustic literature, which states that the risk of unreliable data is high for low noise levels. This variability might also be the result of fact that external noises other than road traffic noise are taken into account, that isolation might introduce a bias between the scientific and the subjective-L_{dn} noise measures, or might be due to different personal sensibility with regard to external noise.
2. A comparison of the "fitted perceived noise" curve with the "scientific traffic noise measure" curve reveals that the slope of the perceived curve is slightly flatter than the 45° line. An explanation for this phenomenon may be similar to those given in the risk evaluation literature (e.g. see Tversky and Kahnemann, 1992; Quiggin, 1982). This literature discusses the implication of systematic biases in individual risk perception and in particular that individuals tend to overestimate low probability events, such as the chance of being struck by lightning, and to underestimate risks of high probability events, such as the chance of dying from heart disease (see Viscusi, 1993). In the hedonic context, the consequence of this systematic bias in individual risk perception is that the marginal compensation that individuals ask for any incremental increase in risk is lower than the marginal compensation they would ask if they were to assess

the risk the same as its scientific measure. In the case of noise, the implicit price of a one decibel increase in perceived noise should be comparatively lower than the implicit price of one decibel increase in actual noise, at any given level of noise. Of course, the final effect on the implicit noise price also depends on the offer curve. As emphasized by Palmquist (2005), the hedonic curve should reflect the market equilibrium as determined by the interactions of house purchasers and real estates owners. We will test this theoretical systematic bias in the empirical part below (Section 4).

3. Sample and Descriptive Statistics

Once we are able to compare perceived and scientific noise measures, our interest is now to discuss the relative performance of each measure within a hedonic model.

In order to obtain the relevant variables, including perceived and scientific noise measures at the apartment level, we gathered the data from different sources of information. Our base dataset is the 2003 statistical information survey on rent structure from the Swiss Federal Statistical Office. This dataset is based on a survey 320 000 randomly selected households, in all regions of Switzerland. The questionnaire used contains detailed questions on the rent and structure of the dwelling, as well as its direct neighbourhood. Originally, the sample for the statistical survey for Geneva included 18 943 observations for the whole canton, both from owners and renters, out of which 7 134 observations were complete (i.e. without missing values) with respect to the structure variables we are interested in. Excluding home-owners, in order to concentrate on the rental market, and recipients of special rent discounts (caretakers, relatives of the property owner, subsidies and members of the real estate cooperative to which the building belongs to) leaves us with 4 348 observations. As discussed in Section 2, the survey responses allowed building a categorical variable measuring the perceived external noise.

This database was then merged with the information on scientific noise measures obtained from the Geneva Cantonal office of protection against noise. Given the fact that these scientific noise data are not available for all streets of the Canton, we loose another third of our sample. Moreover, as common in the acoustic literature (cf. Miedema et al., 1998; 2001), those observations for which the L_{dn} noise exposure lies under 45 dB(A) and above 75 dB(A) were excluded, because scientific noise measures at those levels are unreliable. Finally, 74 outliers were dropped using the Welsch distance criteria. This leaves us 2 794 observations, which is still a relatively large sample considering that it includes both perceived and scientific noise data gathered from different sources.

The third source of information comes from a GIS database, the Information System of the Geneva Territory (SITG). From this database, we computed, for all the buildings of the Geneva Canton, their distance to the nearest park, their distance to the nearest primary school and the percentage of historical buildings in the neighbourhood of the building[5].

[5] We chose to use the statistical sub-sector as the neighbourhood identifier, which is an intermediate territorial entity between the plot and the commune. The density was calculated as the number of historical buildings divided by the surface of the neighbourhood, times one hundred.

Table 2 reports the descriptive statistics of our sample.

Table 2: Descriptive statistics (n = 2 794)

Variable	Mean	Std. Dev.	Min	Max
Mean net monthly rent	1 233	568	177	8 258
Structural variables				
Building was built before 1920	0.199	0.399	0	1
Building was built between 1920 and 1945	0.153	0.360	0	1
Building was built between 1946 and 1960	0.175	0.380	0	1
Building was built between 1960 and 1970	0.205	0.404	0	1
Building was built between 1970 and 1980	0.144	0.351	0	1
Building was built between 1980 and 1990	0.062	0.241	0	1
Building was built between 1990 and 2000	0.062	0.242	0	1
Totally renovated building	0.152	0.359	0	1
Elevator in the building	0.778	0.416	0	1
Privately owned building	0.228	0.419	0	1
Publically owned building	0.033	0.178	0	1
Building belongs to a insurance or a pension fund	0.395	0.489	0	1
Ownership is unknown	0.345	0.475	0	1
Number of floors in the building	7.088	2.695	1	23
Surface of the dwellling (in m2)	79.059	30.694	17	250
Number of rooms	3.098	1.158	1	6
Floor level	3.608	2.569	0	19
Duration of residence (years)	16.206	12.948	2	86
Dwelling with terrasse/garden	0.103	0.305	0	1
Penthouse dwelling	0.064	0.246	0	1
Balcony	0.646	0.478	0	1
Separated toilet	0.239	0.427	0	1
Accessibility variables				
Located downtown	0.689	0.463	0	1
Distance to nearest park (meters)	169.037	137.412	0	1238
Distance to nearest primary school (meters)	212.205	108.589	0	1226
Neighbourhood / Aesthetic variables				
Density of historical buildings	0.730	1.987	0	20.930
View on the lake	0.074	0.263	0	1
View on the mountains	0.477	0.500	0	1
Noise variables				
LrD (dB(A))	65.159	5.249	44	74
Ldn (dB(A))	66.757	5.700	45	75
Subj_Ldn (dB(A))	74.548	4.684	58.963	82.178
Resident-assessed external noise (ranging from 1 to 5)	3.246	1.059	1	5

The mean monthly rent in 2003 was about CHF 1 233 for the whole sample, but its variance is very large[6]. Most of the buildings included in our sample were constructed before 1970, while only 15 per cent of the apartments were totally renovated. 40 per cent of the buildings are owned by an insurance or a pension fund, about 23 per cent are owned by a private person, while 3 per cent are owned by a public entity (commune, canton or confederation). The mean number of rooms, without the kitchen, is about 3.1, with a mean surface[7] of about $80m^2$. The mean duration of residence in the same dwelling is quite long, about 16 years, but the variance is also very large, from 2 to 86 years. This variable has a role to play on the monthly rent, because landlords generally seize the opportunity to raise the rent at changes

[6] Currently, CHF 1 = USD 0.81.

[7] The surface of the dwelling includes the surface of all rooms, kitchen, bathroom, toilet, corridors, and winter garden.

in tenancy. Therefore, the difference between a rent recently contracted and a rent contracted for several years could be substantial (see Thalmann, 1987). Concerning the accessibility variables, constructed by using the GIS data, 69 per cent of the dwellings are located in the city centre, while the mean distance to the nearest park is 170 meters and the mean distance to the nearest primary school is 212 meters. These values illustrate that the size of the Canton of Geneva is small, about 246 square-kilometres in total, so that all infrastructures are relatively concentrated. As neighbourhood and aesthetic variables, the mean density of historical buildings per neighbourhood amounts to 0.7 per cent, with a high concentration of those buildings in the old town, and a remaining few dispersed around the Canton. 7 per cent of the dwellings enjoy a view on the lake, while 47 per cent have a mountain view.[8] The last lines in Table 2 report the summary descriptive statistics related to noise, that we already discussed in section 2.

4. Empirical application and results

In this section, we analyse the performance of perceived vs. scientific noise measures within the hedonic model by using two different procedures. Firstly, we test if the variable coefficients are similar or not depending on which noise measure is used, by estimating, as in Poor et al. (2001), identical equations except for the noise variable. Secondly, we test if the use of the subjective variable adds any explanatory power to the estimation, especially given the fact that this variable incorporates extra information about external noise. In this context, we apply both an instrumentalisation approach proposed by Chattopadhyay et al. (2004) and a classic interaction approach using dummies.

Since the literature does not dictate any functional form for the hedonic equation, it has to be determined empirically. Linear, semi-logarithmic, log-linear, as well as linear Box-Cox transformation are commonly used functional forms. As the linear and the logarithmic functional forms were both rejected by the Davidson-MacKinnon PE-test, Box-Cox transformation of the dependent and independent variables were jointly and alternatively tested, and the semi-logarithmic functional form appears to be the most adequate form, with two transformations in the independent variables. In fact, we allowed for a more flexible functional form by taking the logarithm of the surface of the dwelling and by introducing the square of the duration of residence, in order to account for the non-linearity of the impact of the duration of residence on the rent. The use of the semi-logarithmic functional form for hedonic equation is supported by Malpezzi (2002), for several reasons[9]. More specifically, we estimate the following hedonic equation:

$$\ln Y_i = \alpha + \sum_{m=1}^{M} \beta_{im} z_{im} + \lambda noise_i + u_i \qquad (3)$$

[8] Note that these are subjective perception of the view. Based on GIS data, we are currently defining new original scientific variables in order to be able to characterise the view more precisely than with a dummy variable.

[9] Malpezzi (2002) highlighted five major advantages of the semi-logarithmic functional form: (i) The implicit price of a housing attribute is related to the quantity of the other housing attributes; (ii) The coefficients are easily interpretable in terms of semi-elasticity; (iii) It mitigates heteroskedasticity problems; (iv) It can be computed easily; and (v) Some flexibility in the specification of the independent variables can be easily introduced.

where *ln* Y_i is the natural logarithm of the 2003 monthly rent of dwelling *i*; the vector z_{im} includes the different characteristics (*m = 1, ..., M*) of dwelling *i*, $noise_i$ stands for noise measure at building sheltering *i*; and u_i is an error term reflecting all the unobservable.

In order to test whether we get similar coefficients with different noise measures, we estimate three models, the "Day" model, estimated with the day-time road traffic Lr noise measure; the "Day-Night" model estimated using the day-night noise L_{dn} index; and finally the "Subj-Day-Night" model in which we introduced our subjective-L_{dn} noise measure calculated in Section 2. Therefore, note that we compare both the subjective measure with two scientific noise measures: the day-time traffic Lr noise because it is the reference measure of the Swiss legislation, and the Day-night L_{dn} noise index, which has been used in the literature to better account for annoyance. The estimations of these models for the whole sample of apartments are reported in the corresponding columns of Table 3.

The analysis of simple correlation matrices indicates that there are no significant dependency between the variables, and the variance inflation factor (vif) test, equal to 1.93, confirms that there are no problem of multicolinearity. We used the White's heteroskedastic-consistent estimator of variances because the Breusch-Pagan test rejected the null hypothesis of constant variance (p-value=0.0012). The three alternative models using alternative noise measures produce very similar results. They explain 68 per cent of the variance of rents in the Canton of Geneva. Except for the coefficient of the subjective-L_{dn}, all variables are statistically significant with expected signs. The F-statistics allows the rejection of the null hypothesis that all parameters are jointly equal to zero at the 1 per cent level. Moreover, the coefficients are very stable across the models and tests on the equality of the coefficients, including the noise parameters, between the three models cannot be rejected.

Given the semi-logarithmic function form of the estimated hedonic equation (3), the coefficients of the variables represent semi-elasticities, i.e. the percentage change in the rent for a given unit change in the independent variables, all the other characteristics remaining the same. For instance, the results show that, all else equal, an additional room increases the rent by 12 per cent, while a dwelling with a terrasse/garden will be rented 8 per cent higher. All the other coefficients can be interpreted the same, except the duration of residence and the surface of the dwelling. Since the duration of residence enters with a quadratic effect, the decreasing impact on rent for the mean duration of residence of 16 years amounts to –23.5 per cent. Given that the surface of the dwelling is expressed in logarithm, its coefficient represents the elasticity: a 1 per cent increase in the surface results in a 0.39 per cent increase in the rent.

Table 3: Determinants of rents in the Geneva Canton (n = 2 794)

Model	**Day** (n = 2 794)	**Day-Night** (n = 2 794)	**Subj-Day-Night** (n = 2 794)	**Subj-Obj** (n = 2 794)	**Interaction** (n = 2 763)
Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Structural variables					
Building was built between 1960 and 1970	0.030 **	0.031 **	0.031 **	0.030 **	0.028 *
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Building was built between 1970 and 1980	0.078 ***	0.078 ***	0.079 ***	0.079 ***	0.075 ***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Building was built between 1980 and 1990	0.172 ***	0.173 ***	0.173 ***	0.172 ***	0.173 ***
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Building was built between 1990 and 2000	0.081 ***	0.082 ***	0.083 ***	0.081 ***	0.079 ***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
Totally renovated building	0.040 ***	0.040 ***	0.040 ***	0.040 ***	0.042 ***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Elevator in the building	0.054 ***	0.054 ***	0.054 ***	0.054 ***	0.057 ***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Privately owned building	0.052 ***	0.052 ***	0.052 ***	0.052 ***	0.051 ***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Publically owned building	– 0.153 ***	– 0.154 ***	– 0.154 ***	– 0.153 ***	– 0.155 ***
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Number of floors in the building	– 0.009 ***	– 0.009 ***	– 0.009 ***	– 0.009 ***	– 0.009 ***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Surface of the dwelling (in log)	0.394 ***	0.394 ***	0.394 ***	0.393 ***	0.396 ***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Number of rooms	0.118 ***	0.118 ***	0.118 ***	0.118 ***	0.118 ***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Floor level	0.005 **	0.005 **	0.005 **	0.005 **	0.005 **
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Dwelling with terrasse/garden	0.081 ***	0.081 ***	0.081 ***	0.081 ***	0.080 ***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.017)
Penthouse dwelling	0.086 ***	0.086 ***	0.087 ***	0.086 ***	0.086 ***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
Balcony	0.033 ***	0.033 ***	0.033 ***	0.033 ***	0.032 ***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Separated toilet	0.085 ***	0.085 ***	0.085 ***	0.086 ***	0.084 ***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Duration of residence (years)	– 0.017 ***	– 0.017 ***	– 0.017 ***	– 0.017 ***	– 0.017 ***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Square of the duration of residence (x100)	0.014 ***	0.014 ***	0.014 ***	0.014 ***	0.014 ***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Accessibility variables					
Located downtown	0.074 ***	0.074 ***	0.073 ***	0.073 ***	0.071 ***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Distance to nearest park (km)	– 0.101 ***	– 0.100 ***	– 0.097 ***	– 0.103 ***	– 0.105 ***
	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)
Distance to nearest primary school (km)	0.164 ***	0.165 ***	0.165 ***	0.163 ***	0.164 ***
	(0.047)	(0.047)	(0.047)	(0.047)	(0.047)
Neighbourhood / Aesthetic variables					
Density of historical buildings (x100)	0.567 **	0.559 **	0.561 **	0.586 **	0.593 ***
	(0.232)	(0.231)	(0.231)	(0.233)	(0.231)
View on the lake	0.087 ***	0.087 ***	0.087 ***	0.085 ***	0.087 ***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
View on the mountains	0.026 **	0.026 **	0.026 **	0.026 **	0.022 **
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Noise variables					
LrD (dB(A)) (x100)	– 0.183 **			– 0.214 **	
	(0.094)			(0.094)	
Ldn (dB(A)) (x100)		– 0.150 *			
		(0.088)			
Subjective_Ldn (dB(A)) (x100)			– 0.159		
			(0.108)		
Error of the regression subjective-objective				0.421	
				(0.335)	
*Dummy(no noise)*LrD dB(A)*					– 0.124
					(0.106)
*Dummy(slightly no noise)*LrD dB(A)*					– 0.165
					(0.101)
*Dummy(moderate noise)*LrD dB(A)*					– 0.154
					(0.099)
*Dummy(important noise)*LrD dB(A)*					– 0.167 *
					(0.097)
*Dummy(very important noise)*LrD dB(A)*					– 0.194 **
					(0.095)
Constant	5.111 ***	5.092 ***	5.109 ***	5.134 ***	5.094 ***
	(0.098)	(0.097)	(0.109)	(0.100)	(0.100)
R-squared	0.6827	0.6826	0.6825	0.6828	0.6862
F-stat	245.68 ***	245.75 ***	246.08 ***	238.43 ***	215.18 ***

Notes: *** significant at the 0.01 level; ** significant at the 0.05 level; * significant at the 0.10 level; standard errors in brackets
The reference for the period of construction is a building built before 1960, while the reference for the owner type is composed of insurance, pension funds or unknown owners.

Concerning the impact of noise on rents, an increase by 1 dB(A) reduces the rent by –0.15 per cent to –0.18 per cent, depending on the noise measure used.[10] This result is comparable to the findings from the hedonic studies using scientific measures, applied to the Swiss market, among which Grosclaude and Soguel (1992) who used rental/housing market data from Neuchâtel, Pommerehne (1987) from Basle, Iten and Maibach (1992), Sommer, Suter, Lenz and Salvi (2000) Salvi (2003) from Zurich and Banfi, Horehajava and Filippini (2006) from Zurich and Lugano. All the studies that focused on the impact of road traffic on rents found that noise implies a reduction of the rent, with an estimated average implicit price differentials that varied from –0.19 to –1.26 per cent per increased decibel during the day. Concerning specifically the studies on Geneva rental market, Buechel (1993) found that road traffic noise had a significant negative impact on the apartment rents stemming from the free market, while it had no impact on rent for apartments under state control. Baranzini and Ramirez (2005) found that the impact of road traffic noise on rents did not depend on the scientific noise measure and that for each additional decibel the rent decreased by about 0.25 per cent.

However, we can highlight that in our results, the subjective noise is not statistically significant when the sample contains all noise levels, including relatively low levels. This result is not surprising, given the high variability of perceived noise for low noise levels (see Figure 2 and below).

Since the coefficients of the different noise variables are not statistically different, and remembering that the perceived noise value refers to all sources of external noise, we could conclude that most of the impact of external noise in the Canton of Geneva arises from cars. In order to test more precisely for this phenomenon, we follow the methodology proposed by Chattopadhyay et al. (2004), who used an instrumentalisation approach to show how scientific data can capture various facets of a perceived amenity. In the same vein, we would like to disentangle from the subjective-L_{dn} the external noise arising from road traffic, measured with the scientific data. Therefore, we instrumentalised the subjective-L_{dn} measure with the daytime road noise and estimated the residuals. These residuals can be seen as the pure effect of “other external noise”, i.e. external noise arising from other sources than road traffic. Then, we plugged the residual of this subjective-objective regression into our hedonic equation with the daytime road traffic scientific noise measure. The results of this estimation are reported in the fourth column of Table 3 (Subj-Obj). The statistically significant coefficient of the scientific noise variable is equal to –0.214, while the coefficient of the subjective noise in dB(A) is not significant. This result seems to indicate that there is no additional explanation power of the subjective-L_{dn} variable over the scientific daytime road traffic noise, and that “other external noise” does not have any influence on the rent. If this finding is correct, the

[10] We also performed a regression (not reported here) with the original perceived noise categorical variable. We found that the coefficient of the perceived noise is statistically significant and has a negative impact on the rent of -0.83 per cent, for any increase of one unit in the category. For example, all else equal, a dwelling in which “no external noise” is perceived will be 0.83 per cent more expensive than a dwelling in which “little noise” is perceived. Rieder (2005) used the same information from the 2003 survey on rent structure from the Swiss Federal Statistical Office to fit a nation-wide model. Introducing regional dummies and using spatial econometric techniques, he found that the rent difference between an apartment exposed to external noise and another in a quiet area might be as high as 1.2 per cent.

inclusion of the original perceived external noise data would not improve the estimations either.

To test more specifically for this assumption, we considered the interaction effects between the daytime traffic noise level in dB(A) and the original perceived external noise. To do so, for each category of the perceived external noise we created a separate binary dummy variable and we calculated the interaction terms by multiplying the scientific Lr_D by each dummy. Then we estimated the hedonic model in which we introduced the new interaction terms. The results of this estimation are reported in the fifth column of Table 3 (Interaction). Again the coefficients of all the variables are very stable across the models. It appears that the coefficients of the interaction terms are significant only when the perceived external noise is "important" or "very important". This suggests that the scientific noise measure has an influence on rent, but only when this noise is perceived as important or very important, i.e. for higher level of scientific noise. Moreover, it can be noted that the value of the coefficients of the interaction term increases (in absolute terms) as the perceived external noise increases. However, a Wald test on the joint equality of the interaction terms coefficients cannot be rejected (p-value = 0.3731) and all of the interaction coefficients are individually statistically equal to the coefficient of the daytime noise measure in model "Day" (Lr_D = –0.183) at the 1 per cent level.

The result suggests that introducing perceived noise measures do not improve the estimation outcome and that scientific noise measures approximate them efficiently. However, the result that noise exposure has an impact on rent only when the noise level is high has been treated in the literature and thus deserves some additional comments. In fact, up to this point, we performed the analysis on the whole sample of apartments for which we had the scientific and perceived measures of noise. However, as already discussed in Section 2 and illustrated in Figure 2, the subjective perception presents a lot of variability for low values of L_{dn} (L_{dn}<55). Given the legislation on noise in the different countries, authors have processed data for low noise levels in different ways. For example, Bjorner (2004) performed his contingent valuation study only on those households in Copenhagen that were exposed to noise levels between 55 and 75 dB(A). As UK noise insulation requirements are imposed only for road traffic noise exposure above 68 dB(A), Lake, Lovett, Bateman and Longford (1998) considered noise levels below this threshold to be only background noise level. Hence, they focused their analysis only on those properties exposed to a noise level greater than 68 dB(A). Nelson (2004) stated that although background noise levels of 50 – 60 decibels during the day and 40 decibels during the night are typical in urban areas, it would be erroneous to treat those noise levels as zero, rather than 50 or 60 decibels. The Swiss noise abatement Ordinance sets the noise limit for noise during the day (night) for residential areas to 60 dB(A) (50). In the analysis of the Zurich rental market, Banfi et al. (2006) stated that the night-time road traffic noise levels are calculated only for those streets where noise limit values during the night, i.e. 50 dB(A), have been exceeded. A constraint on the night noise level at 50 dB(A) was therefore implicitly applied. Moreover, the value of 50 dB(A) was assigned to all the buildings in their sample for which the scientific noise level was not calculated, since under the threshold of 50 dB(A), the noise level is considered to be only background noise.

Based on Figure 2, we performed a series of estimations for different truncation points on the background noise level, starting with the threshold of L_{dn}≥55 dB(A)[11]. The coefficients we obtained for all the variables are very similar to those reported in Table 3. Therefore, in Table 4 we only report the coefficients for the noise variables.

Table 4: Changing the background noise truncation point

Truncation points	Obs.	Day	Day–Night	Subj–Day–Night
Ldn ≥ 55 dB(A)	2 612	– 0.215 *	– 0.174	– 0.202
		(0.114)	(0.106)	(0.131)
Ldn ≥ 56 dB(A)	2 551	– 0.219 *	– 0.174	– 0.201
		(0.119)	(0.111)	(0.138)
Ldn ≥ 57 dB(A)	2 476	– 0.299 **	– 0.235 **	– 0.260 *
		(0.127)	(0.118)	(0.145)
Ldn ≥ 58 dB(A)	2 375	– 0.310 **	– 0.238 *	– 0.258 *
		(0.135)	(0.126)	(0.152)
Ldn ≥ 59 dB(A)	2 272	– 0.382 ***	0.288 **	– 0.299 *
		(0.146)	(0.137)	(0.160)
Ldn ≥ 60 dB(A)	2 168	– 0.414 ***	– 0.304 **	– 0.317 *
		(0.158)	(0.146)	(0.175)

Notes: *** significant at the 0.01 level; ** significant at the 0.05 level; * significant at the 0.10 level; standard errors in brackets.
Coefficients reported are multiplied by 100.

From Table 4, we can highlight two interesting results:

1. The coefficients of the model with the scientific measure of the day-time road traffic noise level (model “Day”) are always slightly higher than the coefficients of the model with our calculated subjective-L_{dn} noise measure (model “Subj-Day-Night”), which might parallel the underestimation of high risk discussed in Viscusi (1993) and in the risk literature.
2. The perceived noise coefficients are slightly closer to Lr_D variable (model “Day”) for low noise truncation levels (55 and 56), while for higher truncation points, the perceived noise is closer to the L_{dn} noise index (model “Day-Night”).

However, statistical tests on the equality of coefficients show that, independently of the truncation level, the difference in the coefficients is not significant.[12]

Again we tested for the explanatory power potentials of the three models. Choosing the constraint level of 55, we performed a Davidson-MacKinnon non-nested J-test, used by Poor et al. (2001), on model “Day” and on model “Subj-Day-Night” in order to determine which of the scientific and subjective measures of noise better support the explanation of rent variation. The Davidson-MacKinnon J-test was performed by adding the predicted values from two rival regressions, model “Day” and model “Subj-Day-Night”, as an additional

[11] Basing the truncation point on Lr_D rather than L_{dn} does not change the results.

[12] As we can see in Table 4, the noise coefficients increase (in absolute terms) as the truncation point refers to higher noise levels, which hints at a non-linear relationship between the rent and the noise exposure. However, this non-linear relationship is rejected with a Wald test on the equality of the coefficients. Moreover, we introduced the square of the scientific Lr_D in the estimation, but the coefficient of this new variable was not statistically significant.

explanatory variable in the other model. If the additional regressor is statistically significant in one model, for example model “Subj-Day-Night”, but not in the other, for example model “Day”, then model “Day” is preferred to model “Subj-Day-Night”. This conclusion is motivated by the fact that the influence of the variables in model “Subj-Day-Night”, captured by the fitted value from that model, adds no additional explanatory power beyond that provided by model “Day”. For both models we find that the coefficient of the fitted value from the other model is not statistically significant, suggesting that both models are acceptable.

This result confirms our previous finding obtained with the instrumentalisation methodology and we can conclude that above the threshold of 55 dB(A), both the perceived data, transformed into dB(A), or the scientific measure of noise can safely be used to assess the impact of noise on rents in the Geneva rental market.

6. Conclusion

The aim of this paper was to compare the use of scientific and perceived noise measures in a hedonic model framework. The literature recognises that for property prices to be affected by environmental characteristics, these characteristics have to be perceived by the residents. However, there is no systematic discussion in the literature on the possible biases introduced by using scientific noise measures, which are most commonly used in the literature. We gathered data from different sources in order to obtain a dataset containing both scientific measure and perceived noise data. However, in order to achieve our objective, we needed the different noise measures to be presented in comparable units. Since no such data were available, we referred to the acoustic literature to transform a categorical variable on perceived external noise into a measure directly comparable to a scientific measure of noise in dB(A). We show that a clear relationship appears between the scientific measure of road traffic noise and the transformation of the perceived external noise in dB(A). From this relationship, it is interesting to note that: 1) There is a great variability in the perception of noise when the scientific noise level is relatively low; and 2) The systematic bias of subjective overestimation of low probability events that has been highlighted in the risk perception literature also parallels with our findings here concerning the perceived exposure to external noise.

Then we analysed the performance of perceived vs. scientific noise measures in a hedonic model by fitting alternatively three hedonic models which differed from one another only for the noise measures used, i.e. the daytime road traffic noise, the day-night road traffic noise index or the subjective-L_{dn} in decibels that we calculated using our perceived external noise data. We found that the coefficients of all the variables, including those on noise, are statistically equal across models, although the coefficient of our subjective-Ldn in dB(A) is not statistically significant for low effective noise levels (i.e. a background day-night noise level lower than 57 dB(A), that are often judged as “unreliable” in the acoustic literature). Nevertheless, from the different tests performed on the coefficients of the three different measures, we can confirm the convergent validity of the perceived and scientific noise measures. Then, we tested if the use of the perceived measure adds any explanatory power to the estimation given the fact that our perceived external noise measure was not source specific. With both instrumentalisation and interaction approach techniques, we found that using subjective measure does not improve the estimation, independently of the background noise level considered.

Therefore, we can conclude that for moderate to high noise levels, the scientific measures of noise safely approximate the individual perception of it. Thus a hedonic model using scientific measures will provide results as good as another with subjective noise measure. This result is very promising from a policy-making point of view, for which the use of scientific measures are more convenient and transferable than subjective perceptions.

For lowest noise levels, we note a high variability of the subjective noise perception that can be explained by different factors, among which different subjective sensitivity to noise due to personal or cultural characteristics, the dwelling's isolation or the characteristics of the buildings, and the potential bias between our perceived and scientific noise measures. Preliminary multinomial logit estimation confirmed that there is a positive relationship between the external noise perceived and the characteristics of the building. We are thus currently investigating three additional research questions. Firstly, we would like to explain the subjective noise perception depending on the intrinsic and/or socio-economic characteristics of the individuals. Secondly, our results showed a positive and significant influence of the duration of residence on rents, a duration which varied in our sample from 2 to 86 years. In this context, we are testing whether the changes in tenancy are linked to the perceived noise, the socio-economic characteristics of the households and of their neighbourhoods. Finally, we would like to analyse how to integrate the previous research questions in a hedonic model.

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