The impact of air pollution and noise on the real estate market. The case of the 2013 European Green Capital: Nantes, France

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Abstract: In this paper, we aim to demonstrate the way air pollution and noise may affect the well-being of the inhabitants of Nantes, France, designated the European Green Capital in 2013. We use a database compiling certain attributes of the houses that exchanged hands and their price. In order to understand the complex relationships that can exist between explanatory variables and housing price, we consider not only the direct effects of air pollution and noise on the price of around 3,000 houses sold in Nantes and its metropolitan area from 2002 to 2008, but also the way some location attributes of the dwellings may affect air pollution and noise. We demonstrate that even if air pollution may be affected by some location characteristics of the house, this variable has no significant impact on the price, in the end. Noise is affected by the location of the house and exerts some significant effect on housing price. However, whilst air pollution does not impact at a global level, people who have lived in an air polluted county before coming to Nantes are sensitive to air quality, whereas those who come from a low air polluted county tend to choose low noise exposure dwellings.

Keywords: air pollution, noise pollution, housing location, housing price

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1. Introduction[1]

Air and noise pollution can be considered as two environmental variables that may affect the well-being of inhabitants.[2] There is a large body of evidence about the health impacts of pollution: on the one hand, air pollution has adverse effects on the respiratory and cardiovascular systems as well as a range of other side effects (World Health Organization, 2013); on the other hand, noise exposure can induce hearing impairment, hypertension, annoyance and stress, sleep disturbance, and decreased school performance (Passchier-Vermeer and Passchier, 2000). Because they apply to specific geographical contexts, such annoyances can be assessed by the depreciation we observe on the real estate market. The effects of noise exposure as well as air pollution on housing values are still of interest, even if largely explored (Anselin and Le Gallo, 2006; Bajari et al., 2012; Nelson, 2008).

In this paper, we concentrate our analysis on Nantes, France's sixth largest city. Even if its environmental conditions are as a whole acceptable, due to windy weather linked to its proximity to the Atlantic coast, Nantes is characterized by contrasted environmental conditions regarding noise and air pollution, according to which part of the city is being observed. Over the last two decades, the city of Nantes has developed several policies to make its environment cleaner.[3] Priority was given to a sustainable transport policy, especially public transport, walking and cycling. For instance, Nantes was the first city in France to re-introduce the electric tramway, in 1985. The policy of city-center development aims at minimizing car transport and

[1] We thank the anonymous reviewers for their insightful comments and suggestions on the manuscript.

[2] Concerning air pollution, see Evans et al. (1988), Lercher et al. (1995), Forsberg et al. (1997), Klaeboe et al. (2000), Ambrey et al. (2014). For noise, see Lercher and Kofler (1996), Klaeboe et al. (2000).

[3] The city of Nantes adopted an air quality management plan in 2002, and a climate plan in 2007 whose objective is to reduce greenhouse gas emissions by 30% in 2020 and by 50% in 2025.

increasing pedestrian areas. Furthermore, in 2010/2011 long-term noise polices were implemented.

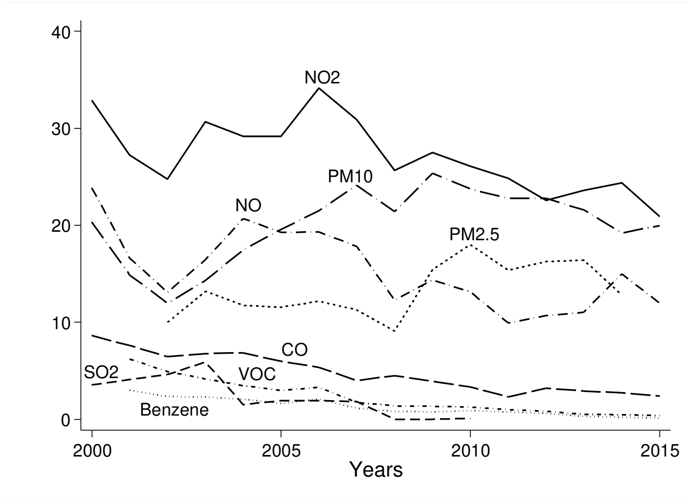

Fig.1 Annual air pollutant concentrations in Nantes (µg/m3, except for CO)

Note: Carbon Monoxide (CO) is in 100µg/m3; VOC: Volatile Organic Compounds (here BTEX). The annual average values are based on the mean values of active measurement stations at this moment: for instance, 13 stations were used for PM_{10} in 2015.

Source: http://www.airpl.org/

As a result of this overall strategy, the levels of most of the main air pollutants have fallen since 2000 (Figure 1), according to the regional agency for air quality (Airpl). Most air pollution indicators (for instance, Carbon monoxide or benzene) remain at levels below the limits set by the European Directive (Directive 2008/50/CE) or the World Health Organization (WHO, 2006). Particulate matter, both between 2.5 and 10 micrometers ($PM_{2.5}$ and PM_{10}) have been relatively stable since 2000. However, some marked differences exist and remain between the different districts of the city.[4] Furthermore, people can be affected by air pollution even if the levels of pollution comply with current WHO guidelines (Lercher et al. 1995).

[4] For instance, the annual average level of NO_2 varies according to the district from 10.53 to 42.41 µg/m_3 in 2008 (Eval-PDU project, 2012). PM_{10} exhibit a similar and contrasting pattern, whereas $PM_{2.5}$ are above the WHO Air Quality Guideline in almost all districts of the city.

Noise disturbance is a negative externality mainly due to transport and this especially occurs in cities near main road transport arteries (OECD, 2001; WHO, 1999). People respond differently to noise disturbance, although they generally tend to be affected negatively when noise levels reach a certain threshold (Dekkers et al., 2009). In Nantes, noise exposure reveals a similar contrasted pattern according to the dwelling location.[5]

Beyond the policies implemented at the public level, the objective of this paper is to study whether the prices of dwellings are influenced by air pollution and noise. Nantes is a city where employment growth is superior to population growth (INSEE, 2014).[6] The aim is to question whether inhabitants coming to Nantes consider air quality and noise as potential determinants of their housing location and as factors of their willingness to pay a premium for their dwellings.

For our purpose, we use the Perval notaries' database linking the price of 2,969 houses that were exchanged in Nantes and its metropolitan area (Nantes *Métropole*) in 2002, 2006 and 2008 respectively, with their intrinsic and extrinsic attributes (location and environmental quality). We consider the facts that firstly, air pollution and noise exposure variables may directly affect the price of a dwelling in local contexts and secondly, that some location characteristics of the dwelling may simultaneously affect air and noise pollution levels. Furthermore, the impacts of

[5] The mean noise exposure varies from around 5 to 75 dB(A), with 65 dB(A) the daily value threshold before noise annoyance becomes noticeable (WHO, 1999). Around 25% of dwellings are above this level.

[6] According to INSEE (2014), Nantes has the second employment growth at the country level (the first for the executives and managers) and the third population growth of the country between 2006 and 2011.

these two annoyances are usually studied separately.[7] To our knowledge, very few studies concern the influence of noise and air pollution together on the prices of dwellings.[8]

We show the existence of a positive but weak relationship between noise and air pollution. Moreover, despite the fact that location attributes affect air pollution levels, these levels do not in turn exert any significant influence on the price of houses that were exchanged in Nantes and its metropolitan area. We emphasize a different result considering noise pollution: it can be affected by some location characteristics of the house purchased, and it simultaneously constitutes a real estate depreciation factor. However, whilst the air pollution variable does not exert any effect at a global level, people who had lived in an air polluted county ('*département*') before coming to Nantes appear to be sensitive to air pollution level. Furthermore, people who come from a low air polluted county choose low noise exposure dwellings. Finally, the importance given to air quality when a house is being purchased tends to increase in line with the age of the inhabitants as well as their previous pollution experience.

This paper is structured in the following manner: in section 2 we present the assumptions. Section 3 is dedicated to the data and the methodology we use, namely a simultaneous equation model. In section 4, we discuss our results and section 5 is devoted to our concluding remarks.

2. Research hypothesis

The way environmental variables may affect the well-being of the inhabitants of some local territories may be assessed by the hedonic pricing method. According to Rosen (1974), housing

[7] An exception is Klaeboe et al. (2000), but the aim of the paper is to assess the combined effects of noise and air pollution on annoyance.

[8] See for instance Le Boennec and Sari (2015), but they use a spatial model approach and the impact of location characteristics on air and noise variables is not taken into account.

price depends on intrinsic attributes of the dwelling (number of rooms, living surface area) and extrinsic ones, such as proximity to public transport, sources of amenities and pollution. The real estate market indirectly provides a monetary value of these attributes. However, the results that may be observed when using the hedonic pricing method appear to be strongly contrasted depending on the variables and the context (Cavailhès, 2005). Whereas intrinsic attributes prove to exert comparable effects on the price of the dwellings regardless of the geographical context, this is no longer the case for location or environmental characteristics.

Concerning noise pollution, a large body of literature indicates that noise exposure has a detrimental impact on housing values.[9] For example, the drop in prices is also about 0.5 per cent per additional decibel emitted by the rail network in Seoul, Korea (Chang and Kim, 2013). Similarly, apartments located in peaceful districts of Paris are worth 1.5 per cent more on average (Bureau and Glachant, 2010). However, depending on the context, the level of noise exposure does not always constitute a significant variable, such as in Grenoble, France, (Saulnier, 2004) and in the majority of the 287 French urban centers studied by Cavailhès (2005).

In hedonic studies, air quality variables often play ambiguous roles. Decker et al. (2005) highlighted the negative impact of high concentrations of restricted pollutants in Nebraska. Still, the same pollutants were not significant in Massachusetts (Bui and Mayer, 2003). Saulnier (2004) did not find any significant relationship between rents and NO_2 levels in Grenoble. This absence of a significant link was generalized by Cavailhès (2005), who found a reduced and possibly zero influence of air pollution on rents in the urban centers studied.

[9] See Taylor et al. (1982), Hughes and Sirmans (1992), Theebe (2004), Dekkers et al. (2009), Chen and Haynes (2015). Furthermore, see Nelson (2008) for a review of hedonic property value studies of transportation noise.

We analyze housing transactions taking place in Nantes *Métropole*, an urban community grouping together 24 communes of the Loire-Atlantique region. It contains around 600,000 inhabitants, half of whom live in the central city of Nantes. At a national level, Nantes *Métropole* is one of the most attractive places to live in the country: its population grew by 4,500 inhabitants each year between 2008 and 2012 (compared with +6,000 inhabitants between 1999 and 2007, according to the National statistical institute). Over the past decade, around one third of newcomers have come from Paris and the Parisian metropolitan area, being characterized by its stronger pollution levels (INSEE, 2014). Nantes was designated the "European Green Capital" in 2013 thanks to its good environmental results.

However in Nantes, unlike numerous other cities, Le Boennec and Sari (2015) did not find any impact of air pollution on the housing values when using the spatial hedonic model. Such contrasted results concerning environmental variables explain why it may be important to look for more complex relationships between explanatory variables. To build location and environmental quality variables, each dwelling location was geo-referenced in the framework of the Eval-PDU project, regarding the environmental impacts of the 2000-2010 urban transport plan of Nantes *Métropole*. Using this original quantitative cross-sectional data, we carried out an econometric analysis based on simultaneous equation modelling. We analyzed the specific influence of some location attributes of the houses exchanged on air pollution and noise exposure levels, which in turn may constitute significant sources of depreciation of the dwelling. More specifically, we tested the following hypothesis (Figure 2):

- The *intrinsic characteristics* of the houses exchanged directly influence their price (Baudry et al., 2009; Bureau and Glachant, 2010). This is generally the case when regarding hedonic literature;

- Certain *location characteristics* simultaneously influence property values (Brécard et al., 2013; Dubé et al., 2013) as well as the levels of noise and air pollution;

- *Air pollution* influences the price of the dwellings, and may as well be affected by location attributes of the houses exchanged;

- *Noise pollution* influences the price, and may as well be affected by location attributes.

The three last assumptions in particular better emphasize the way some variables exert an influence on housing price, transiting by specific interactions that are ignored when using the classic hedonic pricing method.

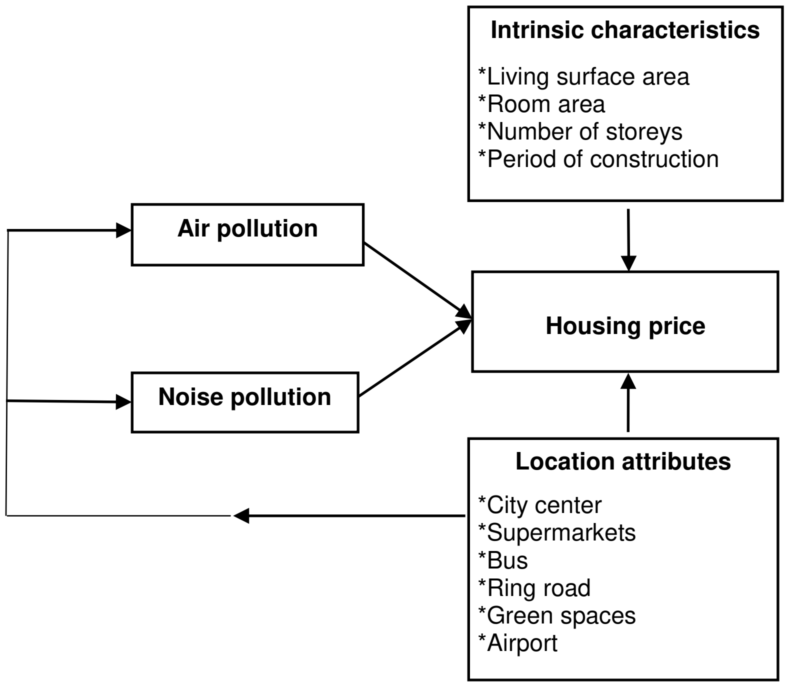

Fig.2. The hypothesized relationships between the variables

3. Material and Methods

3.1 Description of the data

The Perval notaries' database allows us to link the price of houses that were exchanged in Nantes *Métropole* with some specific characteristics (Figure 2). The database gives information on the transactions (price, date, type of negotiation, nature of the transfer, etc.), on location (district of the house, land registry reference, etc.) and on the intrinsic attributes of the accommodation (type of house, number of rooms, living surface area). Certain details concerning the purchasers are provided as well (age, and previous location).

After rationalizing the database, the analysis involved 2,969 house transactions. According to Table A.1, the houses have a mean living surface area equal to 112.82 square meters with an average room area equal to 21.84 square meters. More than 65% of the houses are two-storey houses and 22% of the houses were built between 1981 and 1991.

Regarding location, the geo-referencing included the geographical location of the dwellings and a large set of reference places (railway stations, green spaces, etc.). Several distances variables expressed in kilometers were retained: distance to the city center, central station, tram, campus, airport, commercial zone, green space or access to the ring road around the city. Furthermore, the number of bus stops within a distance of 100 meters was also taken into consideration.[10]

The natural environment is generally of good quality. The mean distance from a green space is equal to 330 meters (Table A.1). Conversely, houses in Nantes *Métropole* are diversely served by public transport: 34% are less than 2 kilometres from a railway station, 38% have a bus stop less than 150 meters away, but only 15% have a tram stop less than 450 meters away. The

[10] We do not retain the distance to the nearest bus stop due to correlation problems with tram stops and railway stations (tram stops and railway stations have bus stops).

correlation matrix between theses distances is presented in Table 1. Some accessibility criteria are strongly correlated in the upper part of the matrix: distance to the city center, station, tram, or campus.[11] We considered the log mean value of these four variables to compile the distance to the city center.

Table 1. Accessibility criteria correlation matrix (in kilometers)

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
City center	**(1)**	1.000							
Railway station	**(2)**	0.967	1.000						
Tram	**(3)**	0.909	0.890	1.000					
Campus	**(4)**	0.819	0.875	0.818	1.000				
Airport	**(5)**	0.416	0.281	0.340	-0.042	1.000			
Commercial zone	**(6)**	0.395	0.366	0.390	0.315	0.173	1.000		
Green space	**(7)**	0.089	0.067	0.064	-0.003	0.210	0.152	1.000	
Ring road	**(8)**	0.322	0.334	0.312	0.306	0.083	0.091	-0.006	1.000

Note: the number of observations is equal to 2969.
Source: Eval-PDU

The noise exposure levels to road and rail noise were calculated from the traffic data. Each road was decomposed in homogenous parts in terms of noise emission. The traffic data were completed with speeds, acceleration or deceleration of cars, the surfacing and the slope of the road. From each homogenous part of the road, we calculated the standardized noise level in agreement with the Annex 1 of the European Directive 2002/49/CE relating to the assessment and management of environmental noise.[12] The minimum, mean and maximum noise values (respectively) were individually calculated on each of the three periods of the day (daytime, evening, night-time). Afterwards they were compiled to calculate the minimum, mean and maximum levels (respectively) of the synthetic noise index in the form and using the weights advocated by the Directive. Around 25% of houses are subject to disturbing and excessive noise

[11] For these variables, the Cronbach's alpha statistic, which determines the internal consistency of items in a survey instruments to determine its reliability, is equal to 0.96. According to Nunnally (1978), a score of 0.70 obtained on a substantial sample is an acceptably reliable coefficient.

[12] http://www.developpement-durable.gouv.fr/IMG/pdf/Texte_de_la_Directive-2002-49_CE-2.pdf

(greater than 65 dB(A), WHO (1999)) at some point during the day (maximum noise over 24 hours, Figure 3). The mean noise level of the synthetic index was retained.[13]

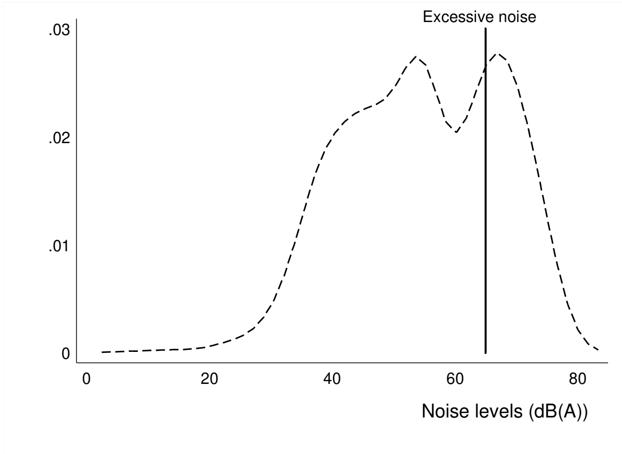

Fig.3. Distribution of noise levels dB(A)
Note: Gaussian kernel function is used (bandwidth=2.5)
Source: Eval-PDU

The air pollution levels around the dwellings subject to a transaction were calculated. The concentration of several airborne pollutants described in Table A.2 was simulated using the Atmospheric Dispersion Modelling System (ADMS Urban model). In this model, road traffic, residential and tertiary emissions are regarded as a major source of air pollution at urban scales. The retained pollutants are Nitrogen dioxide (NO_2), Nitrogen oxides (NO_x), Particulate matter (PM_{10} and $PM_{2.5}$), Carbon monoxide (CO), benzene (C_6H_6), Volatile organic compounds (VOC), and Sulphur dioxide (SO_2). The pollutants of interest are in particular NO_x, PM_{10} and $PM_{2.5}$. They take into consideration the Euro5 (2011) and Euro6 (2015) standards for diesel vehicles and their controversial effectiveness on air quality. The ADMS Urban model for NO_x chemistry includes reactions with ozone and hydrocarbons.[14] A Lagrangian trajectory model

[13] For each of the 2969 observations (for which we know the mail address), we were able to obtained and identify the Nantes Métropole actual noise levels for 2008. The Spearman's rank correlation coefficient is equal to 0.78 (the conurbation uses an ordinal scale to characterize the actual noise levels). The null hypothesis of independence between actual and simulated noise levels is rejected at the .0001 level. The actual and simulated noise levels are highly correlated and we suppose that simulated noise levels reflect individual preferences.

[14] More precisely, the NO_x chemistry is modeled using the eight reaction Generic Reaction Set (for details, see Venkatram et al., 1994). The NO_x chemistry offers the possibility to get accurate predictions of NO_2.

including the effects of emissions, chemistry, and deposition is used to calculate background concentrations for the air approaching the main modelling area.

The ADMS Urban model integrates lots of emission sources simultaneously. Road emissions were calculated for segments of roads, depending on the traffic flow and the mean speeds of different categories of vehicles, as well as the technical characteristics of the road (the effect of street canyons and traffic-induced turbulence). Residential and tertiary emissions were based on combustion and the use of solvents by households and firms' employees (depending on the population and the nature of the housing stock). Finally, a variety of meteorological data were taken into account to reflect seasonality (with for instance lower pollution levels during summer) (Figure 4).

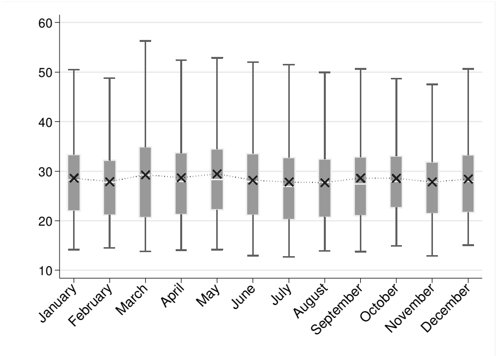

Fig.4. Box plot of NO_x concentration (µg/m^3) by months

Note: The dashed line represents the mean. The upper/lower limit is the largest/lowest value not greater than third/first quartile +/- 1.5 × Interquartile range.
Source: Eval-PDU

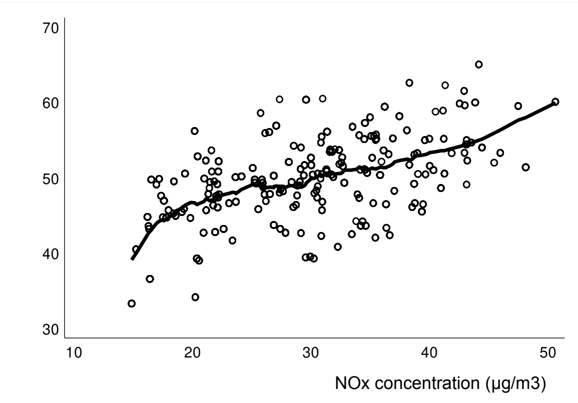

Fig.5. Average noise level (dB(A)) and NO_x concentration (µg/m^3) by district

Note: The curve is obtained by symmetric nearest neighbor linear smoother.

Most of air pollution mean values for the city of Nantes and its metropolitan area are under the annual Air Quality Guideline (AQG) of the WHO (2000, 2006): this is notably the case for the NO_2 (the AQG equals to 40 µg/m^3) and the PM_{10} (20 µg/m^3). Only the $PM_{2.5}$ mean value is above the AQG (10 µg/m^3). For the NOx, the French quality objective is equal to 30 µg/m^3. In our sample, around 40% of the dwelling transactions took place where the air pollution level was above the AQG. As showed by Figure 4, the NO_x concentration is characterised by a strong disparity. This dichotomy is also notable when considering the mean NO_x concentration by district (Figure 5).

Before investigating the role of these two factors on the price of houses, we have to analyze the potential link between noise and air pollution, as road traffic induces most of air pollution and noise. As expected, Figure 5 shows an upward sloping noise/air pollution relationship by district (NO_x concentration). This relationship is obtained through a kernel smoother. Yet the R^2 is only 0.3. Finally, the correlation matrix is presented in Table A.2 to take into account the potential links between these pollutants. According to Table A.2, the air pollution criteria are strongly correlated. The Cronbach's alpha statistic was computed and is equal to 0.99. Finally, we consider the mean value of all normalized pollution criteria to construct the air pollution variable.[15]

3.2 Methods

The price of the house was retained as the dependent variable (in a logarithmic form). From the descriptive analysis of the data, we postulate that the price can be explained by several factors.[16] We introduce in a simultaneous equation model the effect of certain intrinsic characteristics, some location attributes (see above distance variables), and environmental variables (the air pollution construct and the log of mean noise level variable). Using such a model, we are willing to take into account the path analysis and recursive nature of the relationships between the

[15] The coefficient of correlation between the noise variable and the air pollution construct is equal to 0.36. Even if air and noise pollution are mainly an effect from road traffic, their coefficient of correlation is low because their propagation models are different (wave mechanics for noise *vs* fluid mechanics for air).

[16] The hedonic literature alternately consider rents or housing prices as a dependent variable. Comparable results may be noticed concerning in particular intrinsic attributes (number of rooms, parking facilities…). See for example Cavailhès (2005) for rents in 287 French cities or Bureau and Glachant (2010) for housing prices in Paris.

variables (Figure 2).[17] This is useful for testing multiple sets of associations between variables simultaneously. The model can be written as:

$$P_i = \alpha + \gamma X_i + \beta W_i + \delta Z_i + \phi Y_i + \varepsilon_i \quad (1)$$

$$Z_i = \mu + \lambda W_i + \omega_i \quad (2)$$

$$Y_i = \nu + \varphi W_i + \vartheta_i \quad (3)$$

where P_{i} is the vector of prices (in logarithm) that vary between transaction *i*. X_i is a vector of intrinsic characteristics, W_i a vector of location attributes, Z_i a vector of atmospheric characteristics, Y_i a vector of noise characteristics. α, μ, ν, γ, β, δ, ϕ, λ, and φ are the corresponding parameters to estimate. ε_{i}, ω_{i}, υ_i are residual error terms (expected to be uncorrelated with the explanatory variables).

A correlation matrix on the independent variables was performed (Table A.3). As several variables are correlated (for instance, noise and air pollution or air pollution and distance to the city center), the Variance inflation factor (VIF) statistics were calculated. They show that the model does not suffer from multicollinearity as all VIF statistics are lower than 5 which is often taken as threshold (Chatterjee and Hadi, 2012).

The presence of spatial dependency was tested in our set of data. The Moran's I statistics is equal to 1.66 (exactly the 10% significance level). We conducted afterwards both the Spatial Error Model (SEM) and the Spatial Autoregressive Model (SAR). In the latter case, it appeared that the value of the spatial parameter never significantly differed from zero. For the SEM estimation, the likelihood ratio test comparing the non-constricted and the constricted models

[17] This path analysis model is treated as a seemingly unrelated regression which allows for the simultaneous estimate of the coefficients and carries out estimates of the standard errors that take into account the contemporaneous correlations.

generally concluded to the absence of significant spatial autocorrelation between the independent variables.[18] Given the global results obtained respectively to the Moran-s I statistics and to the likelihood ratio tests, we concluded to the absence of significant dependency in our sample.

Furthermore, as residuals are heteroscedastic and not normally distributed, the Huber-White standard errors were used and the model was estimated with quasi-maximum likelihood estimation. Moreover, the independent variables are by assumption measured without error. As both air pollution and noise are simulated data, the presence of measurement error may lead to biased and inconsistent parameter estimates (Fuller, 1987). In our case, we tested an error-in-variables regression model in presence of independent variable measured with error. The significance levels are similar to the model measured without error.

4. Results

The results for the whole model are presented in Table 2. In Table 3, several variables linked to buyers' characteristics are used.

In hedonic studies, the intrinsic attributes such as living surface area, the number of rooms or parking spaces, the age of the building usually influence the price of houses or apartments (Baudry et al., 2009; Bureau and Glachant, 2010; Cavailhès, 2005). For Nantes *Métropole*, the results show that the living surface area not surprisingly plays a positive role on the price. Furthermore, the average room area, the two-storey houses (compared to single-storey house),

[18] The result of the test was usually between 0 and 2.23, to be compared to the 5% significance level for the Chi-square test with one degree of freedom: 3.84. Only two specific calibrations of the neighborhood matrix performed a test comprised between 3.40 and 3.89.

and the age of the houses (for houses built after 1991 compared to houses built before 1948) are on average conversely linked to the price as well as the distance to the city center.

The original result of the paper consists in the explanation of air pollution and noise exposure levels. These two variables are assumed to explain the price of the house. In the second and third columns of Table 2, the variables at stake in such an explanation are analyzed.

Table 2. Estimation results

	Price	Environmental variables	
		Air	Noise
Environmental variables			
Air pollution	0.071		
	(0.103)		
Noise	-0.035**		
	(0.018)		
Intrinsic characteristics			
Living surface area	0.950***		
	(0.024)		
Average room area	-0.009***		
	(0.002)		
Single-storey house (reference)	Ref.		
Two-storey house	-0.055***		
	(0.012)		
Three-storey house or higher	0.003		
	(0.023)		
House built before 1948 (reference)	Ref.		
House built between 1948 and 1969	-0.047**		
	(0.018)		
House built between 1970 and 1980	-0.024		
	(0.018)		
House built between 1981 and 1991	-0.024		
	(0.019)		
House built after 1991	0.098***		
	(0.018)		
Location attributes			
Distance to city center	-0.112***	-0.143***	-0.087***
	(0.016)	(0.002)	(0.010)
Distance to commercial zone	-0.010	-0.013***	0.022***
	(0.008)	(0.002)	(0.007)
Number of bus stops	0.003	0.002**	0.012***
	(0.004)	(0.001)	(0.004)
Distance to ring road	0.007	0.004**	-0.004
	(0.007)	(0.002)	(0.008)
Distance to green space	-0.0003	-0.0005*	-0.001
	(0.001)	(0.0002)	(0.001)
Distance to airport	0.075***	-0.010***	-0.013
	(0.011)	(0.002)	(0.012)
Constant	8.278***	1.558***	4.592***
	(0.206)	(0.026)	(0.139)
Temporal effects (monthly effects)	Yes	Yes	Yes
Number of observations		2969	
Pseudo Log-Likelihood		-37584.818	

Note: Robust standard errors are in parenthesis. * p<0.1, ** p<.05, *** p<0.01.
Source: Eval-PDU

The influence of *air pollution* in the formation of house prices in Nantes is not as evident, probably because of the satisfactory level of air quality. Air pollution regarded as the dependent variable can be explained by the distance to the city center: the closer the house exchanged is located to the center, the poorer air quality. This is also the case when the house is located near a commercial zone. In such areas, the high level of airborne pollutants (excluding ozone) is due to the numerous cars circulating during peak hours that aggravates air pollution. This is also the result of the simultaneous presence of industrial firms. The presence of diesel light delivery trucks at other times of the day constitutes another source of aggravated air pollution.

The number of bus stops exerts a significant impact on air pollution. Those areas also see a high number of cars circulating. Such reconfigured areas may have contributed to diminish the mean speed of the remaining cars. Indeed the large initial place devoted to cars has often been transferred to public transport and clean transport modes. Yet traffic jams prove to add to air pollution.

Surprisingly, the proximity to the ring road leads to the opposite result. The relative quality of air around the city is probably due to the fact that the road network in the less densely populated areas is less built-up. In the absence of congestion, cars travelling at higher speed on the ring road (rather than more slowly on inner streets) may be considered less pollutant as well.

The case of *noise pollution* is more interesting. According to our results, the amplitude of the effect of noise on housing price remains low: 1% increase in dB(A) should induce a decrease equal to around 0.035% of the price.

When noise is regarded as the dependent variable, it would seem worthwhile to compare the same potential explanatory variables as for air pollution. Being located next to the city center constitutes a significant factor for aggravation of noise pollution: cars, buses, trams, but also pedestrians shopping or having leisure time in coffees or restaurants prove to be numerous sources of noise from the morning to late at night.

Surprisingly, this is no longer the case for the proximity to a commercial zone, as it was emphasized for air pollution: a house located next to a mall appears to be less affected by noise than the same house located farther. This could be the result of specific peak hours for consumer activities in such areas (mostly in the evening). Such a pattern would have an impact on the maximum noise level, but not on the mean level, considering parallel and majoritarian calm hours during the rest of the day and at night.

As expected, the number of bus stops in the neighborhood, as for air pollution, exerts a positive effect on the average noise level. The coefficient is higher than for air pollution because buses are particularly loud when they leave stations compared to cars (whereas in Nantes they tend to pollute less than cars because they use natural gas instead of fuel). This is also the result of high concentrations of people waiting for the bus, especially schoolchildren which may be regarded as unruly by the inhabitants early in the morning. The distance to the ring road, to the nearest green space or to the airport have no significant impact on the mean noise level.[19]

Table 3. Estimation results to certain characteristics of purchasers

	Air pollution		**Noise**			
	Coeff	**SE**	**Coeff**	**SE**	**N**	**PLL**
Total	0.071	0.103	-0.035**	0.018	2969	-37584.82
Age						
Less than 40 years	0.125	0.135	-0.070***	0.026	1485	-18247.69
40 to less than 55 years	0.202	0.173	-0.054	0.031	980	-12353.77
55 years and more	-0.387**	0.189	0.065	0.043	504	-6312.63
Anterior air pollution level						
High	-0.630**	0.314	-0.003	0.047	199	-1954.61
Low	0.099	0.108	-0.035*	0.107	2770	-35222.20

Note: *p<0.1, **p<.05, ***p<0.01. SE: Standard errors, N: Number of observations, PLL: Pseudo-LogLikelihood.
Source: Eval-PDU

[19] Concerning the ring road, the positive impact of being remote from the city center and having less built-up road and tram networks is offset by the proximity to a major road, where fast cars appear to be loud on average (with the exception of peak hours). The expected quietness of green spaces is offset by car-parking in the neighborhood and by numerous households living elsewhere. For the airport, only a very small part of our sample is located in the air corridor. For all the other dwellings, the mean noise level due to air traffic proved to be below the disturbance limit.

Finally, we use two variables linked to buyers' characteristics: their age and whether their last dwelling was situated in a polluted county.[20] Table 3 gives the coefficients of air pollution and noise estimated in the same simultaneous model as before, conditioned to certain characteristics. Young people appear to pay more attention to noise levels when they buy a house, whereas old people seem to be more sensitive to air pollution. This result is partly in line with the results from Menz and Welsch (2010), which show that the preferences for air quality are U-shaped in age with epidemiological evidence on the age-specific health consequences of air pollution. Furthermore, people who lived in air polluted counties before coming to Nantes (especially Paris) appear to be more sensitive to air pollution levels, whereas those who come from low air polluted counties are more inclined to choose a house with low noise exposure. This result confirms the result from Menz (2011) which showed, in an environmental valuation, that past pollution levels increase the value of clean air.

5. Concluding remarks

In this paper, we tested the assumption of the way environmental variables could be simultaneously affected by specific attributes of the houses exchanged in Nantes and its metropolitan area, and could affect housing price. We showed that air pollution had no significant impact on the price, whereas noise pollution does have an impact. Air pollution still depends on the proximity to the city center or to a commercial zone, and on the structure of the individual or public transport network. The relationships between such characteristics and noise pollution prove to be more complex: noise strongly depends on the proximity of the city center

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[20] The Perval database gives information on the age and the municipality of residence. For each municipality of residence belonging to a county, we have used the National Atmospheric index scaled from 1 to 5 (high pollution refers to an index superior to 3).

or the number of bus stops in the neighborhood. This seems to reinforce the depreciation impact noise pollution significantly exerts on housing price in Nantes *Métropole*.

Moreover, whereas noise is directly perceptible, the reason for which air pollution has no effect on house prices may be due to: first, the largely invisible and intangible nature of air quality (except for instance when it is odorous or visible, like for certain industrial smokes, or when its effects are tangible for people who suffer from coughs or other forms of irritation); and second, to the fact that air quality is seen as being ephemeral (even though the effects of air pollution on health are tangible). Even if French urban citizens have begun to be suspicious about invisible pollution since the end of the 19th century (Massard-Guilbaud, 2003), air pollution resulting from traffic or industry may be thought of as impossible to tackle as it is anonymous, permanent, and linked to modernity (Barraqué, 1997). Furthermore, the process of measuring invisible and toxic pollution remained in the technical domain until recent years, over which atmospheric pollution have steadily become a political issue (Frère et al., 2005).

As Nantes is a dynamic city, the housing demand has seen important growth since the 2000s. Prospective purchasers may have fewer options for choosing property and may not have the choice between different dwellings with similar attributes but with significant differences in noise or air pollution levels. For instance, as noted by Blanco and Flindell (2011), the advantages of living in noisier or more polluted areas closer to specific facilities (closer to the city center or a commercial zone for instance) outweigh the assumed negative effects of the consequently higher noise or air pollution levels. If purchasers are prepared to accept higher pollution levels as unavoidable consequences of living closer to facilities, then there might be no reason for the price to be affected (Blanco and Flindell, 2011). As we have no information about the motivations, perceptions, and preferences of the buyers, a study taking these elements into account should contribute to better understand the impact of environmental variables on the real estate market.

Annex

Table A.1. Descriptive statistics

	Mean	SD	Min	Max
Intrinsic attributes				
Living surface area (square meters)	112.82	42.26	32.00	650.00
Average room area (square meters)	21.84	6.00	7.50	125.00
Single-storey house	0.26	0.44	0	1
Two-storey house	0.66	0.47	0	1
Three-storey house or higher	0.08	0.27	0	1
House built before 1948	0.19	0.39	0	1
House built between 1948 and 1969	0.20	0.40	0	1
House built between 1970 and 1980	0.21	0.41	0	1
House built between 1981 and 1991	0.22	0.41	0	1
House built after 1991	0.18	0.39	0	1
Location attributes (kilometers)				
Distance to city center	6.55	3.46	0.35	19.92
Distance to station	6.67	3.63	0.35	20.94
Distance to tram	2.74	2.57	0.03	13.70
Distance to campus	5.17	3.52	0.29	19.97
Distance to airport	9.61	3.88	0.83	23.67
Distance to commercial zone	0.76	0.61	0.01	5.23
Distance to green space	0.33	0.27	0.01	1.92
Distance to ring road	2.18	1.21	0.15	8.69
Number of bus stops	1.84	1.43	0	7
Atmospheric pollution (μg/m³)				
Nitrogen dioxide (NO_2)	19.85	4.41	10.53	42.41
Nitrogen oxides (NO_x)	28.35	9.13	12.70	121.05
Particulate matter (PM_{10})	16.81	0.83	15.33	24.68
Particulate matter ($PM_{2.5}$)	11.37	0.66	10.17	17.54
Carbon monoxide (CO)	470.20	31.54	425.40	732.63
Benzene (C_6H_6)	0.23	0.15	0.02	1.52
Volatile Organic Compounds (VOC)	8.90	4.90	1.32	49.41
Sulphur dioxide (SO_2)	1.29	0.51	0.27	4.06
Noise pollution (dB(A))				
Max	54.77	12.62	5.48	80.34
Mean	49.12	11.71	4.69	74.50
Min	32.52	14.76	0.02	73.86

Note: the number of observations is equal to 2969. SD: standard deviation.
Source: Eval-PDU

Table A.2. Air pollution concentrations correlation matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Nitrogen dioxide	**(1)**	1.000							
Nitrogen monoxide	**(2)**	0.947	1.000						
Particulate (PM_{10})	**(3)**	0.942	0.997	1.000					
Particulate ($PM_{2.5}$)	**(4)**	0.944	0.996	0.999	1.000				
Carbon monoxide	**(5)**	0.913	0.969	0.976	0.977	1.000			
Benzene	**(6)**	0.909	0.966	0.973	0.974	0.998	1.000		
Organic compound	**(7)**	0.914	0.967	0.973	0.974	0.992	0.993	1.000	
Sulphur dioxide	**(8)**	0.971	0.926	0.927	0.930	0.927	0.926	0.933	1.000

Note: the number of observations is equal to 2969.
Source: Eval-PDU

Table A.3. Correlation matrix of the variables included in the model

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Air pollution	**(1)**	1.000																	
Noise	**(2)**	0.366	1.000																
Living surface area	**(3)**	0.069	0.023	1.000															
Average room area	**(4)**	0.100	0.032	0.455	1.000														
Single-storey house	**(5)**	-0.197	-0.062	-0.295	-0.013	1.000													
Two-storey house	**(6)**	0.023	0.033	0.130	-0.027	-0.823	1.000												
Three-storey house or higher	**(7)**	0.276	0.042	0.248	0.067	-0.177	-0.413	1.000											
House built before 1948	**(8)**	0.254	0.036	-0.067	0.083	-0.038	-0.059	0.164	1.000										
House built between 1948 and 1969	**(9)**	0.193	0.059	-0.091	0.033	0.098	-0.102	0.020	-0.184	1.000									
House built between 1970 and 1980	**(10)**	-0.121	-0.016	0.072	-0.038	0.035	-0.014	-0.032	-0.189	-0.257	1.000								
House built between 1981 and 1991	**(11)**	-0.157	-0.053	-0.053	-0.121	-0.013	0.082	-0.122	-0.194	-0.265	-0.272	1.000							
House built after 1991	**(12)**	-0.157	-0.022	0.079	-0.009	-0.054	0.109	-0.103	-0.174	-0.237	-0.243	-0.250	1.000						
Distance to city center	**(13)**	-0.735	-0.170	0.037	-0.018	0.155	-0.046	-0.168	-0.173	-0.200	0.108	0.097	0.112	1.000					
Distance to commercial zone	**(14)**	-0.367	-0.016	0.041	-0.019	0.126	-0.035	-0.141	-0.147	-0.143	0.067	0.118	0.120	0.317	1.000				
Number of bus stops	**(15)**	0.191	0.085	0.002	0.002	-0.082	0.049	0.045	0.013	0.069	0.003	-0.036	-0.068	-0.179	-0.197	1.000			
Distance to ring road	**(16)**	0.026	-0.008	0.007	0.020	-0.005	-0.013	0.030	0.085	0.022	-0.029	-0.042	-0.021	0.035	-0.020	0.033	1.000		
Distance to green space	**(17)**	0.018	-0.007	-0.020	0.017	0.010	-0.027	0.031	0.072	0.012	-0.021	-0.005	-0.100	-0.030	-0.082	0.033	0.025	1.000	
Distance to airport	**(18)**	-0.155	-0.039	0.101	-0.006	-0.111	0.130	-0.047	-0.133	-0.096	0.065	0.115	0.061	0.311	0.084	-0.003	0.017	-0.133	1.000

Note: the number of observations is equal to 2969.
Source: Eval-PDU

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