Accessibility, local pollution and housing prices. Evidence from Nantes Métropole, France

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Abstract – In this empirical article, we analyze the extent to which accessibility and environmental variables are capitalized in apartment prices in Nantes Métropole, France. Using a sample of 5,590 transactions in 2002, 2006, 2008 from the *Perval* database, we estimate a spatial hedonic price model that takes into account spatial autocorrelation and spatial heterogeneity. Special attention is also paid to the construction of environmental quality variables (noise exposure, air pollution). We find that apartment prices depend positively on proximity to Nantes city centre but that the public transport network (urban or non-urban) has no significant influence. Noise reduction is valued, but only at low or marginal levels of significance. Last, air quality does not significantly influence apartment prices. These results can be related to good accessibility and environmental quality in Nantes Métropole which probably makes households less sensitive to these issues than in other geographical contexts. This seems to provide little support for sustainable urban mobility plans favoring better accessibility, unless public authorities also target the greater awareness of the use of virtuous modes of transport.

JEL Classification: C21, Q51, Q53, R31
Keywords: hedonic price model, accessibility, air quality, noise exposure, spatial econometrics

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Elected the European Union's Green capital in 2013, Nantes is now part of "Green cities fit for life". Nantes also ranks in the top French cities in which to live, according to a number of different French surveys[1]. One of its strengths is its environmental performance, thanks to urban transport networks, air quality, a quiet environment and the development of green spaces in the city. To what extent do households value these determinants of their living environment? This issue is particularly relevant with respect to the effectiveness of local policies, which are in theory aimed at enhancing the inhabitants' well-being via improvements in accessibility, air quality and calm, amongst other quality-of-life factors.

The theoretical urban economics literature suggests that accessibility and environmental amenities are key in household location decisions. The analysis of the determinants of household location relative to Central Business Districts (CBDs) reveals a trade-off between housing centrality – cheaper for the same surface area further from the centre – and transport costs – higher further away from the centre – (Alonso, 1964; Ogawa & Fujita, 1980; Le Boennec, 2014). When there are multiple CBDs, the fall in housing prices with distance to the city centre may no longer be monotonic (Osland & Pryce, 2012; Le Boennec & Sari, 2015). Location choice also takes amenities into account (Fujita, 1989; Takahashi, 2017; Lemoy *et al.*, 2017), while negative external environmental factors (noise, congestion and air pollution) discourage location (Kanemoto, 1980; Schindler *et al.*, 2017).

The hedonic pricing method has been widely used since the seminal article of Rosen (1974) to provide monetary values for housing's intrinsic and extrinsic attributes. As house prices depend on intrinsic (number of rooms, living surface area) and extrinsic (proximity to public transport, social quality of the neighborhood, amenities and pollution) attributes, the housing market can indirectly provide a monetary value for these attributes. The price difference between two dwellings that are identical with the exception of one attribute should reflect the value of the gain or loss of well-being induced by that attribute: public transport, an amenity or environmental quality. The hedonic pricing method is therefore especially relevant for the provision of new insights into households' willingness-to-pay for greater accessibility and environmental quality.

Empirical work using stated preferences has also underlined the significance of these amenities in housing decisions. Households select the environments with transport and amenities that are consistent with their preferences (Bhat *et al.*, 2008; Cao & Cao, 2014). The role of preferences is revealed in residential location choices (Lund, 2006; Walker & Li, 2007). Preferences are related to the life cycle, in the sense that certain life events (for example, the birth of a child) may change preferences and thus drive individuals to move (Clark & Onaka, 1983; Rabe & Taylor, 2010).

A wide-ranging empirical literature has used the hedonic approach in order to assess the values of both intrinsic and extrinsic house attributes. Although the bulk of the work using the hedonic pricing method has been carried out in the United States and Canada, the European literature has been growing since the early 2000s and even more recently; it is the same in Asia. In France, Cavailhès (2005) highlights that housing values rise with amenities and accessibility in the rental market in 287 French urban centres. He underlines that these higher values depend greatly on the social quality of the neighborhood. Capitalization of access to public transport in apartment prices has been shown in Nantes (Fritsch, 2007) and Paris (Nguyen-Luong & Boucq, 2011). The roles of environmental amenities (such as green spaces) and environmental damage (such as noise exposure) have also been highlighted in Grenoble (Saulnier, 2004), in the majority of the urban centres studied by Cavailhès (2005), in Paris (Bureau & Glachant, 2010), in Angers (Choumert & Travers, 2010; Travers *et al.*, 2013), on the French Atlantic coast (Pouyanne *et al.*, 2011; Le Berre *et al.*, 2017) and in Nantes (Le Boennec & Sari, 2015; Le Boennec & Salladarré, 2017).

Location and accessibility attributes often count among the major determinants of housing prices. Still, it is not always the case depending on the local context, whereas in most cases, the positive or negative relationship between accessibility to certain amenities or transport facilities and real-estate capitalization has to be clarified. Concerning environmental quality variables, there exist very few French hedonic studies providing insights

1. *See for instance the 2018 Express ranking, where Nantes is in first place, as was the case in 2017 (https://www.lexpress.fr/emploi/le-palmares-2018-des-villes-ou-il-fait-bon-vivre-et-travailler_1984924.html, accessed 20/03/2018).*

on the potential influence of air pollution or noise exposure on the price of dwellings (see the following Literature review section). Even scarcer are the studies where corresponding data could be calculated for every dwelling transaction. Investigating such original variables, the present article provides new insights into the effects of greater accessibility and environmental quality on apartment values in a local context: the conurbation of Nantes Métropole.

To implement the hedonic model, we rely on an original cross-sectional database partially obtained from numerical simulations. These were carried out as part of a wide multidisciplinary research project, using a chain of physically-based models. The starting point of these was traffic data in Nantes Métropole (Mestayer *et al.*, 2012), and noise exposure and air quality around dwellings were calculated. These environmental data were matched to our geo-referenced database, which includes data on apartment transactions in the 24 communes of Nantes Métropole in 2002, 2006 and 2008, and distances to a set of reference points.

As housing observations constitute a type of data characterized by location attributes, we apply spatial econometrics in relation to hedonic price modeling. The spatial dependence between observations in our sample is then taken into account at various points in space. In order to deal with spatial autocorrelation and spatial heterogeneity, we use the instrumental variables and Generalized Method of Moments approaches (GMM) proposed by Kelejian and Prucha (2010) to estimate annual spatial autoregressive models with unknown heteroscedasticity in the disturbances. This recent multi-step estimation method has a spatial autoregressive process in the dependent variable and disturbance term.

In line with the existing hedonic literature, our results confirm that intrinsic attributes have an impact on housing prices. Concerning extrinsic attributes, the results are far more mixed: if greater accessibility to Nantes city centre increases apartment prices as expected, we find no significant impact of the public transport networks (both urban and non-urban) on prices. The specific influence of environmental quality variables is very limited as well: we find that airborne pollutants do not reduce housing prices; noise pollution does, but it only leads to slightly lower prices for noisy compared to quiet apartments. Some of these results are quite surprising and will be discussed further.

The remainder of the article is structured as follows. The next section reviews the current literature pertaining to the effect of noise, air pollution and accessibility on housing values. Then we present our database. Another section explains the econometric model and the spatial dependence tests, and the next is dedicated to the analysis of the results. Last, we provide some concluding remarks and policy recommendations.

Literature review

Although empirical work using the hedonic pricing method is relatively unanimous regarding the impact of various intrinsic attributes on housing values, results are more divided on the effects of extrinsic attributes, which crucially depend on dwelling location and neighborhood. The scope of this review is limited to the extrinsic attributes that will be investigated in the present article, namely local pollution (noise and air) and access to urban and non-urban public transport.

Noise

As a negative externality, noise tends to reduce housing values. Nelson (2004) considers the effects of noise exposure in dwellings close to 23 airports in the United States and Canada. He finds an average drop in house prices of 0.58% per additional decibel (dB), with greater noise sensitivity in Canada. The literature review in Nelson (2008) emphasizes that the Noise Depreciation Index (NDI) has a median value of 0.74% per dB for aircraft noise and 0.54% for traffic noise. Andersson *et al.* (2010) show a larger negative effect of road noise than railway noise in the Swedish municipality of Lerum, with a respective fall of 1.2% and 0.4% in property prices per additional dB. This figure rises to 1.7% for road noise and 0.7% for railway noise when the total noise level is over 55dB. This drop is also about 0.5% per additional dB from the rail network in Seoul, Korea (Chang & Kim, 2013). In the same line, apartments located in calmer districts in Paris, France, are worth 1.5% more on average (Bureau & Glachant, 2010). However, the relationship between noise exposure and housing values is not always obvious. Le Boennec and Sari (2015) find only a weak relationship between exposure to road and rail noise and house prices in Nantes Métropole (-0.23% per additional dB). Depending on the context, noise is sometimes even not significant, as found in Grenoble, France (Saulnier, 2004) and by Cavailhès (2005) in the majority of the French urban centres.

Air pollution

The relationship between air pollution and housing values has been extensively investigated since the seminal article of Ridker and Henning (1967), who established a negative effect of sulphur pollution in the St. Louis metropolitan area, United States. Air quality variables produce widely-differing effects on housing values in hedonic analyses (Smith & Huang, 1993; Boyle & Kiel, 2001). Decker *et al.* (2005) find a negative impact of a high concentration of restricted pollutants in Nebraska, United States. However, the same pollutants are not significant in the other American State of Massachusetts (Bui & Mayer, 2003). French studies have also revealed a not significant link between air pollution and housing values: between nitrogen dioxide levels and rents in Grenoble (Saulnier, 2004) and air pollution and rents in French urban centres (Cavailhès, 2005). Kim *et al.* (2003) show that a permanent 4% improvement in air quality, through lower sulfur dioxide pollution (SO_2), is valued at 1.43% of mean house price in Seoul, whereas NO_x pollution does not play any role in housing values. These contrasting results likely reflect heterogeneity in housing markets. Using a particular air-quality index, Le Boennec and Salladarré (2017) find that house buyers in Nantes Métropole are generally not sensitive to air pollution, except for those who previously lived in an air-polluted area. The mixed results could also come from differences in air quality measurement. For instance, Anselin and Le Gallo (2006) show that discrete ozone categories produce better results than the associated continuous variable in the estimation of the effect of air quality on housing values in Southern California.

Transportation

Empirical work on access to public transport (urban and non-urban) has produced contrasting results. This is emphasized by Bowes and Ihlanfeldt (2001) for Atlanta, United States. Railway station proximity is likely to increase house prices via improved accessibility and the presence of neighborhood shops, which is an advantage for nearby inhabitants. However, railway stations produce noise and air pollution, and disturb the landscape. The global net effect is therefore negative for properties close to the railway station (within a quarter of mile) and positive for properties farther away (between one and three miles). Other work has also found this concave effect of proximity to railway stations, such as Billings (2011) for light rail in Charlotte, United States, and Mohammad *et al.* (2017) for the subway in Dubai, United Arab Emirates. However, the positive accessibility effect dominates the negative externality effect for light rail in most of the studies focusing on other cities in the United States (for a detailed survey see Efthymiou & Antoniou, 2013, and Dubé *et al.*, 2013) and cities in Asian countries (Pan & Zhang, 2008; Chen & Haynes, 2015; Li *et al.*, 2016; Diao *et al.*, 2017).

Similar results have been obtained in European cities. Efthymiou and Antoniou (2013) show that proximity to subway, tram, suburban and bus stations in Athens, Greece, increases apartment prices, whereas proximity to the old urban railway, national rail stations, airports and ports reduces prices. Martínez and Viegas (2009) find that subway proximity increases property values in Lisbon, Portugal, with access to two subway lines being valued more than access to a single line. In Paris, while proximity to a railway station increases prices (Bureau & Glachant, 2010), proximity to a subway station reduces them. This is in line with Nguyen-Luong and Boucq (2011), who find 5% lower prices for apartments located within 200 meters of the third line of the Paris tram. Interestingly, Fritsch (2007) uncovers similar results in Nantes, where tram lines tend to reduce housing values in areas near the city centre and increase housing values farther away[2].

The meta-analyses of Debrezion *et al.* (2007) and Mohammad *et al.* (2013) show that the effects of rail projects or existing infrastructures on housing values also depend on a number of other factors, such as the type of rail service, the age of the rail system (with older networks having more lines and so being more attractive to users), the characteristics and locations of the stations, and the geographical location and access to roads. In particular, Mohammad *et al.*

2. Fritsch (2007) does however use a very particular definition of district accessibility: this is considered to be high (respectively medium and low) when the apartment is located in an IRIS where more than 50% (respectively from 20 to 50% and less than 20%) of the IRIS surface is within 300 meters as the crow flies of a tram stop.

(2013) show that commuter rail has larger positive effects on land and property values than light rail, and that access to roads reduces the valuation of rail. Moreover, the impact of rail is higher in European and East Asian cities compared to those in North America.

Description of the data

The determinants of Nantes Métropole apartment prices are analyzed using cross-sectional data. Nantes Métropole is an urban community bringing together 24 communes of the Loire-Atlantique *département* in the Pays de la Loire *région*. It is located in the West of France, 380 km from Paris, and covers over 523 km². It is crossed by one major river (the Loire), and two other rivers (the Erdre and the Sèvre). It counts 600,000 inhabitants, half of whom live in the central commune of Nantes. There were over 2.3 million daily trips in 2015 in this territory, 55% of which were by car (both drivers and passengers) and 15% by public transport. The total traveled distances were 21 km a day, corresponding to a total travel time of 67 minutes[3]. The database allows us to link the prices of apartments that were sold in Nantes Métropole to their intrinsic and extrinsic attributes (accessibility, geographical and socio-economic environment and environmental quality). All of the descriptive statistics appear in Table 1.

The data come from the notaries' *Perval* database, providing information on the 25,000 transactions of apartments and houses in Nantes Métropole in 2002, 2006 and 2008[4]. It is worth noting that all housing transactions in any part of France are covered by two notarial databases: *Perval* and by the *BIEN* database for Paris (Gouriéroux & Laferrère, 2009). The data were geo-referenced as part of the multidisciplinary research project. We use here data on the 5,590 apartment transactions, after cleaning the data from missing information. As real-estate transaction data cannot be treated as continuous over time, the three years are considered separately. The data provide information on the transaction (date, price, nature of the transfer, etc.), the location of the apartment (commune, cadastral plan section, etc.) and its intrinsic attributes (surface area, number of main rooms, bathrooms, etc.). Regarding the surface area, all the observations were kept with the exception of one apartment, whose surface area was under 9 m².[5]

The geographical and socio-economic environment of the apartments is described by contextual data from the French National Institute of Statistics and Economic Studies (Insee). These data are at the "Aggregated blocks for statistical information" level (*Ilots Regroupés pour l'Information Statistique* or IRIS): apartment and house density, the unemployment rate, median income in the IRIS, the percentage of the population who are over 60, foreigners, and have higher education, and the presence of a so-called Sensitive Urban Zone (*Zone Urbaine Sensible* or ZUS) in the IRIS or the contiguous IRIS.

Both general and specific accessibility attributes were geo-referenced as part of the multidisciplinary research project. These include the Euclidian distance to a set of reference places (railway stations, campus, etc.), to public transport networks (bus, tram and non-urban train), green spaces, rivers and Nantes city centre. The three watercourses constitute natural geographical barriers. This is notably the case for the Loire that workers living South of the river have to cross, as the majority of jobs are found to the North. Only 17% of housing transactions took place South of the Loire, considering the three years of transaction. 88% of apartments are inside the ring road, located on average around 6 km from the city centre. The natural environment is generally of good quality: 87% of apartments are located less than 600 meters from a green space (the average surface area of the latter is a little over 4 ha). Apartments are well-served by public transport: 46% are within 2 km of a railway station, 25% have a bus stop less than 100 meters away, and 48% have a tram stop less than 500 meters away[6].

3. *Source: Travel Survey in Loire-Atlantique* département*, January 2016.*

4. *Our descriptive data reveal a price of €1,866 per square meter for 2008 apartment transactions. This figure was €1,511 in 2002 (in constant Euros), and €1,984 in 2006. The two-year fall in price between 2006 and 2008 is thus -5.9%. On the contrary, prices per square meter rose 31.3% between 2002 and 2006. The real-estate market in France did not fall as sharply as in Spain, Ireland or the United States, for example. This favorable outcome is partly due to the dynamic long-term housing demand in France (and especially in large urban areas like Nantes Métropole), which is a result of demographics. Another reason may be the high level of public spending in France, which helped to preserve households' purchasing power during the global financial crisis.*

5. *The French decree of 2002, 30th January specifies the minimal surface area that a dwelling owner is allowed to rent to be qualified as decent: this minimal surface area is 9 m². Moreover, the* Loi Carrez *(Carrez law) aims at certifying the surface area of dwellings that are sold in France (to be occupied by the owner or not): this certification is mandatory from 8 m². This is thus not a surprise if the* Perval *database contains 95 observations less than 20 m², as Nantes is an attractive city for students studying in the large university of Nantes and other institutions of higher education. This situation is comparable in France not only in Paris, but also in other large metropolises throughout the territory (Lyon, Toulouse, Montpellier, Rennes, Lille, etc.).*

6. *These percentages are quite similar for the three years under consideration.*

Table 1
Descriptive statistics

		2002				2006				2008			
Variable	Definition	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Surface area	Living surface area in m^2	64.49	24.67	11.00	241.00	62.03	24.97	12.00	242.00	61.56	25.03	13.00	250.00
Constr<1948	Construction before 1948	0.03	0.16	0.00	1.00	0.05	0.22	0.00	1.00	0.05	0.21	0.00	1.00
Constr[1948-1969]	Construction 1948-1969	0.18	0.39	0.00	1.00	0.20	0.40	0.00	1.00	0.20	0.40	0.00	1.00
Constr[1970-1980]	Construction 1970-1980	0.19	0.39	0.00	1.00	0.20	0.40	0.00	1.00	0.19	0.39	0.00	1.00
Constr[1981-1991]	Construction 1981-1991	0.14	0.35	0.00	1.00	0.15	0.36	0.00	1.00	0.12	0.33	0.00	1.00
Constr>1991	Construction after 1991	0.46	0.50	0.00	1.00	0.40	0.49	0.00	1.00	0.44	0.50	0.00	1.00
Sale bef. completion	Sale before completion	0.34	0.47	0.00	1.00	0.22	0.41	0.00	1.00	0.22	0.42	0.00	1.00
No parking space	0 parking space	0.04	0.19	0.00	1.00	0.06	0.23	0.00	1.00	0.08	0.28	0.00	1.00
One parking space	1 parking space	0.82	0.39	0.00	1.00	0.83	0.37	0.00	1.00	0.80	0.40	0.00	1.00
>One parking space	2 parking spaces or more	0.15	0.36	0.00	1.00	0.11	0.31	0.00	1.00	0.12	0.32	0.00	1.00
ZUS	Location in a ZUS	0.04	0.20	0.00	1.00	0.06	0.24	0.00	1.00	0.06	0.25	0.00	1.00
Contiguous ZUS	Location in an IRIS contiguous to a ZUS	0.14	0.35	0.00	1.00	0.17	0.38	0.00	1.00	0.16	0.37	0.00	1.00
House density	House density in the IRIS in ha	6.51	4.62	0.00	16.43	7.11	4.79	0.00	17.54	6.69	4.68	0.00	17.07
Median income	Median income in the IRIS in €	18,765	3,215	8,170	28,059	18,481	3,636	8,441	29,015	18,917	3,472	8,565	28,799
Distance centre	Distance to the city centre in m	3,166	1,994	177	13,209	3,330	2,063	43	13,213	3,332	2,176	55	13,445
Dist. railway station	Distance to the closest railway station in m	2,529	1,635	93	10,048	2,457	1,559	110	10,221	2,574	1,755	129	10,078
Dist. bus	Distance to the closest bus stop in m	165	105	15	609	158	93	16	633	169	101	18	612
Tram<500m	Presence of a tram stop less than 500 m away	0.47	0.50	0.00	1.00	0.47	0.50	0.00	1.00	0.49	0.50	0.00	1.00
Private road	Location on a private road	0.30	0.46	0.00	1.00	0.32	0.47	0.00	1.00	0.28	0.45	0.00	1.00
Green spaces	Green-space surface area less than 300 m away in m^2	13,307	23,672	0.00	123,856	15,646	25,210	0.00	140,907	15,471	24,382	0.00	140,907
Max. noise	Maximum noise in 24 hours in dB	61.86	10.50	22.55	87.38	62.32	11.19	14.54	94.40	62.56	11.58	8.36	86.68
Benzene	Maximum concentration of	0.20	0.09	0.04	0.74	0.20	0.10	0.04	0.90	0.20	0.09	0.03	0.67
CO	ditto	346.5	25.8	301.4	469.2	346. 6	26.3	300.8	534	346.5	25	297.8	493
VOCs	ditto	10.44	3.21	3.27	27.7	10.38	3.24	3.07	31.02	10.43	3.22	2.64	24.65
NO_2	ditto	22.14	3.53	11.29	33.58	22.00	3.67	11.32	39.46	22.07	3.67	10.43	35.82
NO_x	ditto	34.18	8.80	14.84	74.17	34.19	9.05	14.69	94.76	34.19	8.62	13.16	77.33
PM_{10}	ditto	19.09	0.85	17.28	23.36	19.11	0.87	17.25	25.00	19.10	0.83	17.13	23.34
$PM_{2.5}$	ditto	11.99	0.67	10.55	15.27	12.00	0.69	10.54	16.65	12.00	0.66	10.44	15.39
SO_2	ditto	1.88	0.24	1.06	2.54	1.87	0.25	1.05	2.51	1.86	0.29	1.04	2.44

Note: SD = Standard deviation.
Coverage: 5,590 apartment transactions in the 24 communes of Nantes Métropole in 2002, 2006 and 2008 (respectively 1,943, 1,981 and 1,666 observations).
Sources: *Perval* 2002, 2006 and 2008.

Last, environmental quality variables were constructed as part of the research project. There are two of these. First, the exposure of apartments to road and rail noise: minimum, mean and maximum noise levels in the three periods of the day (daytime, evening, night-time), and over 24 hours. Second, the concentrations of eight airborne pollutants that are primarily associated with road traffic: sulfur dioxide (SO_2), nitrogen oxide (NO_x), nitrogen dioxide (NO_2), particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), benzene, Volatile Organic Compounds (VOCs). The minimum, mean and maximum annual concentration levels of these were calculated.

Exposure to road and rail noise was calculated from traffic data as the standardized noise level, in accordance with Appendix 1 of the European Directive 2002/49/CE relating to the assessment and management of environmental noise[7]. The minimum, mean and maximum noise values were calculated for each of the three periods of the day. These were then compiled to produce the corresponding levels for the synthetic noise index using the weights advocated by the Directive (Le Boennec & Salladarré, 2017). It is worth noting that about

7. *http://www.developpement-durable.gouv.fr/IMG/pdf/Texte_de_la_Directive-2002-49_CE-2.pdf.*

half of apartments are not subject to noise problems, at any point during the day (below 65dB as the maximum noise over 24 hours)[8].

The Atmospheric Dispersion Modelling System urban model (ADMS) includes a number of emission sources simultaneously. We included road emissions, as they are expected to be major contributors, as well as residential and tertiary emissions. A variety of meteorological data were also taken into account to reflect seasonality (Le Boennec & Salladarré, 2017). Correlations were calculated to take into account the potential links between the pollutants. The air pollution criteria are strongly correlated for each year of transaction (the correlations between pollutants are at least equal to 0.75). This may be due to underlying factors which could be observed through a factor analysis[9]. Using the Kaiser criterion, one factor emerges from the analysis for each year, and more than 95% of the variance is explained by this factor. Finally, we use the factor score of all pollution criteria for each year to construct the air pollution variable[10]. Most of the mean values of air pollution for the central city of Nantes and its metropolitan area are below the annual Air Quality Guideline (AQG) of the World Health Organization (2000; 2006). However, around 15% of dwellings are on average above this threshold. We retain a dummy variable reflecting these 15% of locations concerned with air pollution.

In order to emphasize potential clusters of prices among close observations, we perform Local Indicators of Spatial Autocorrelation, or LISA, on apartment transactions (Figures I-A, I-B and I-C). The LISA statistics measure the degree of similarity of each observation to its neighbors (Anselin, 1995, 2005). We calculate separate LISA statistics for each of the three transaction years, using GeoDa. A variety of spatial weight matrices were tested[11].

The results show comparable clustering patterns of prices for the three transaction years. Around half of the samples present significant patterns of local clustering (57.9% in 2002, 52.1% in 2006 and 48.8% in 2008). Positive spatial autocorrelation in our samples is emphasized in the form of clusters of high prices on one side, and clusters of low prices on the other side. Clusters of high prices are found for 11.8% of all transactions. The corresponding apartments are located on the one hand in the Western districts of the central part of the city and, on the other hand, in the Northern part. These districts generally have high household incomes and benefit from good amenities (green spaces and private roads). On the contrary, clusters of low housing values emerge in the peripheral districts of the conurbation (21.2% of the observations), where social housing is found in the form of tower blocks dating from the 1960s and 1970s. When negative spatial autocorrelation occurs, it can be found mainly in intermediate districts: a majority of the 20% of transactions with low-high or high-low clustering values can be found between central and peripheral districts, indicating that in such areas, a minority of cheap (respectively costly) apartments have costly (respectively cheap) apartments in their neighborhood.

Nearly half of the remaining transactions (47%) do not have significant LISA values, so that highlighting local spatial autocorrelation for these observations is delicate. These transactions are also mostly located in intermediate districts of the city. However, these results should be taken with caution. There are other techniques, like scan tests, that may prove to be more sensitive in the detection of local clustering patterns (Hanson & Wiczoreck, 2002). Indeed, while LISA statistics are expected to systematically suggest clustering patterns, they may also emphasize single significant observations, as they are calculated for each transaction. However, as we do not want to advocate a maximum number of observations per cluster (which is a requirement for scan-test processing), we prefer to rely on LISA statistics (López *et al.*, 2015). Therefore, we retain for each transaction year five dummies corresponding to the five clustering patterns of prices emphasized by LISA statistics (high-high, low-low, low-high and high-low apartment prices, and not significant values). In the next section, the inclusion of these variables in our model will be tested.

8. Exposure to airborne noise was not taken into account, as only a few apartment transactions in our sample were located in the air corridor.
9. The Bartlett test of sphericity concludes that a factor analysis is relevant for each year. The Kaiser-Meyer-Olkin measure of sampling adequacy is 0.82 in 2002, 0.81 in 2006, and 0.80 in 2008, indicating that the sampling method is adequate.
10. Cronbach's alpha statistic determines the internal consistency of items in a survey instrument to determine its reliability. This statistic is 0.76 in 2002 and 2006 and 0.77 in 2008. According to Nunnally (1978), a score of 0.70 obtained on a substantial sample is an acceptably reliable coefficient.
11. We retain the weight matrices we use afterwards for the spatial estimation. The LISA maps were thus produced using 60 nearest neighbors in 2002, 100 in 2006 and 40 in 2008.

Figure I
LISA cluster maps for the apartment prices in Nantes Métropole (2002, 2006 and 2008)

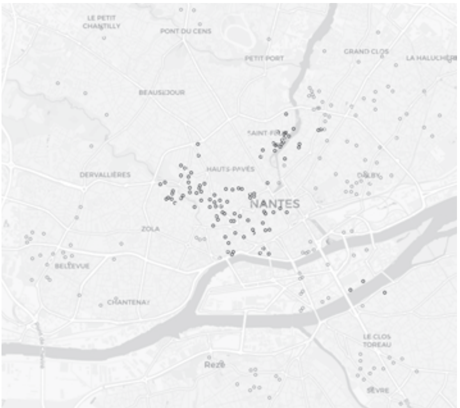
A – 2002

1,943 observations (2002, 60 nearest neighbors)

B – 2006

1,981 observations (2006, 100 nearest neighbors)

C – 2008



1,666 observations (2008, 40 nearest neighbors)

Note: *High-High* (in black): the observed values of the transaction and its neighbors are high; *Low-Low* (in grey): the values of the transaction and its neighbors are low. Not represented: *Low-High*: the value of the transaction is low but those of its neighbors are high; *High-Low*: the value is high but those of its neighbors are low. LISA statistics are significant at the 5% level.
Source: Authors (GeoDa).

Empirical model

We use the apartment price as the dependent variable. From the descriptive analysis of the data, we postulate that this price can be explained by the intrinsic attributes of the dwelling, and extrinsic attributes such as proximity to public transport, which is a source of both amenities and pollution. We use the following hedonic price model to estimate housing price effects:

$$p_i = \alpha_0 + \sum_{c=1}^{C} \beta_c x_{ci} + \sum_{q=1}^{Q} \gamma_q y_{qi} + \sum_{r=1}^{R} \delta_r z_{ri} + \sum_{s=1}^{S} \phi_s v_{si} + \varepsilon_i \quad (1)$$

Here p_i is the log of the price of transaction I, x_c are the C intrinsic attributes of the apartment sold, y_q the contextual variables, z_r the accessibility characteristics et v_s the environmental quality variables. α, β, γ, δ, and ϕ are the corresponding parameters to be estimated, and ε_i is a residual error term assumed to be independent and identically distributed. All of the intrinsic and extrinsic variables described (Table 1) were included in the empirical model. Among the intrinsic attributes, the surface area and its square were additionally considered to test for a potential nonlinear relationship with the price[12].

As the assumption of independence between observations is often violated, hedonic price models frequently use spatial econometric

12. *The surface area and its square were centered to reduce the correlations between the variables.*

methods applied to geo-referenced data (Cliff *et al.*, 1975; Anselin, 1988; Le Gallo, 2002, 2004). We tested the assumption of spatial dependence (*i.e.* cross-unit interactions), which implies that the structure of the correlation matrix between apartments located in different places is determined by the relative position of these apartments in geographical space. In other words, the values observed in one place depend on those elsewhere.

First, following the empirical strategy in Chasco *et al.* (2018), an Ordinary Least Squares (OLS) regression of the variables presented in Table 1 is estimated for each year. In addition, quarterly period dummies are included as temporal effects, as well as five submarket dummies corresponding to the five clusters of prices emphasized in the preceding section (on this point, see López *et al.*, 2015). Table 2 provides OLS estimates and a number of regression diagnostics to test non-normality, heteroscedasticity, and especially spatial dependence. Each model explains more than 80% of the apartment price variance. According to the AIC and BIC criteria, the spatial submarket dummies improve the model fit.

The models are not greatly affected by multicollinearity, as shown by the low value of the mean Variance Inflation Factor or VIF index (which is under 5 for all variables). However, the condition index is above the acceptable limit of 30-40 (Belsley, 1991). The Shapiro-Wilk and Cook-Weisberg tests indicate non-normality in the error terms. According to the Breusch-Pagan test for heteroscedasticity, we can reject the assumption of homoscedasticity for the three models, suggesting a functional form of heteroscedasticity. As a special case of the Breusch-Pagan test where the assumption of normally-distributed errors is relaxed, the White test provides similar results and shows the existence of an unspecified form of heteroscedasticity.

A number of tests were carried out to analyze the spatial autocorrelation that represents the correlations between the value at a location and those at neighboring locations. The Moran's I Error Test is significant, suggesting a problem with spatial autocorrelation in the residuals. The Lagrange Multiplier (LM) tests for spatial autocorrelation as well as their robust counterparts were calculated for an inverse distance matrix and different sets of nearest-neighbor

Table 2
Empirical estimation of apartment prices - OLS results and regression diagnostics

Model	2002	2006	2008
Surface area	0.0161** (0.0004)	0.0145** (0.0003)	0.0152** (0.0003)
Surface^2	-0.0062** (0.0005)	-0.0055** (0.0004)	-0.0053** (0.0006)
Constr<1948	-0.2395** (0.0400)	-0.1124** (0.0295)	-0.1331** (0.0360)
Constr[1948-1969]	-0.2384** (0.0199)	-0.1758** (0.0150)	-0.2157** (0.0157)
Constr[1970-1980]	-0.2696** (0.0209)	-0.1571** (0.0150)	-0.2190** (0.0165)
Constr[1981-1991]	-0.1201** (0.0185)	-0.0748** (0.0159)	-0.1185** (0.0163)
Sale before completion	0.1847** (0.0172)	0.1869** (0.0134)	0.2007** (0.0148)
No parking space	-0.1539** (0.0553)	-0.0916** (0.0261)	-0.1609** (0.0301)
>One parking space	0.0370** (0.0119)	0.0377** (0.0144)	0.0074 (0.0163)
ZUS	-0.0913** (0.0331)	-0.0693** (0.0199)	-0.0161 (0.0239)
Contiguous ZUS	-0.0387** (0.0144)	-0.0262** (0.0099)	-0.0359** (0.0129)
Median income	0.2976** (0.0394)	0.1662** (0.0282)	0.2492** (0.0342)
Private road	-0.0155 (0.0107)	-0.0320** (0.0085)	-0.0128 (0.0098)
Green spaces	0.0042** (0.0011)	0.0005 (0.0009)	0.0018+ (0.0011)
Distance centre	-0.0575** (0.0121)	-0.0582** (0.0103)	-0.0891** (0.0129)

➔

Table 2 (contd.)

Model	2002	2006	2008
Dist. railway station	0.0486** (0.0091)	0.0290** (0.0072)	0.0234* (0.0097)
Distance to bus stop	0.0873* (0.0403)	-0.0078 (0.0066)	0.0138 (0.0086)
Tram>500m	-0.0306 (0.0683)	0.0071 (0.0098)	-0.0021 (0.0104)
Max. noise	-0.0007+ (0.0004)	-0.0014** (0.0004)	-0.0013** (0.0004)
Air pollution	0.0321+ (0.0182)	0.0244 (0.0152)	0.0308* (0.0153)
Temporal effects			
Second quarter	0.0186 (0.0155)	0.0242* (0.0101)	0.0045 (0.0123)
Third quarter	0.0420** (0.0134)	0.0411** (0.0104)	-0.0024 (0.0129)
Fourth quarter	0.0475** (0.0147)	0.0459** (0.0121)	-0.0163 (0.0131)
Spatial submarkets			
Submarket 2 *(High-High)*	0.1310** (0.0210)	0.1596** (0.0182)	0.1223** (0.0203)
Submarket 3 *(Low-Low)*	-0.0607** (0.0140)	-0.0281** (0.0106)	-0.0544** (0.0121)
Submarket 4 *(Low-High)*	-0.0628* (0.0254)	-0.0613** (0.0237)	-0.0770** (0.0225)
Submarket 5 *(High-Low)*	0.0805** (0.0136)	0.1103** (0.0129)	0.0467** (0.0148)
Constant	8.6513** (0.3920)	10.4452** (0.2829)	9.8130** (0.3516)
Observations	1,943	1,981	1,666
R-squared	0.832	0.822	0.823
Model fit			
AIC	-664.96	-1293.05	-886.97
BIC	-508.95	-1136.49	-735.26
AIC (Model without spatial submarkets)	-560.98	-1159.39	-806.98
BIC (Model without spatial submarkets)	-427.25	-1025.20	-676.94
Multicollinearity			
Mean VIF	1.78	1.58	1.59
Condition index	86.6	77.0	66.7
Error normality			
Shapiro-Wilk W test	0.848**	0.905**	0.970**
Heteroscedasticity			
Breusch-Pagan	51.84**	63.40**	159.35**
White's test	735.38**	590.22**	521.81**
Spatial error			
Moran's I Error Test	14.09**	11.04**	18.54**
RLM Error (5 nn)	109.64**	72.00**	206.16**
RLM Error (10 nn)	112.41**	69.39**	327.88**
RLM Error (20 nn)	108.95**	98.69**	373.45**
RLM Error (40 nn)	107.88**	93.33**	333.30**
RLM Error (60 nn)	86.56**	71.68**	260.49**
RLM Error (100 nn)	76.48**	42.66**	254.27**
Spatial lag			
RLM Lag (5 nn)	3.28*	1.49	4.43**
RLM Lag (10 nn)	4.44*	2.69	0.53
RLM Lag (20 nn)	5.96**	3.04	9.38**
RLM Lag (40 nn)	9.46**	0.23	24.08**
RLM Lag (60 nn)	13.12**	3.50	7.49**
RLM Lag (100 nn)	7.52**	4.98*	17.02*

Note: ** Significant at 1%, * Significant at 5% and + Significant at 10%. RLM are the Robust Lagrange Multiplier tests for spatial error and spatial lag models. 5 nn (nearest neighbors), 10 nn, 20 nn, 40 nn, 60 nn and 100 nn are the 5, 10, 20, 40, 60 and 100 nearest-neighbor weight matrices, respectively. *High-High*: The observed values of the transaction and its neighbors are high; *Low-Low*: the values of the transaction and its neighbors are low. *Low-High*: the value of the transaction is low but those of its neighbors are high; *High-Low*: the value is high but those of its neighbors are low.
Coverage: 5,590 apartment transactions in the 24 communes of Nantes Métropole in 2002, 2006 and 2008 (respectively 1,943, 1,981 and 1,666 observations).
Sources: *Perval* 2002, 2006 and 2008; authors' estimations.

matrices (5, 10, 20, 40, 60 and 100)[13]. 60 nearest neighbors were chosen for 2002, 100 for 2006, and 40 for 2008[14]. The robust LM test for spatial errors is significant, as well as the robust LM test for the spatial lag. The first is always higher than the second. However, these results must be taken with caution due to the non-normality of the error terms.

In accordance with the results of the LM tests, we use a spatial model containing spatial lags in the dependent variable, exogenous variables and disturbance term. The spatially-lagged variable allows for spatial spillovers in the dependent variable; it uses a spatial weight matrix to express the potential spatial interaction between the locations of each pair of apartments[15]. Moreover, a spatial autoregressive process is included in the error term, allowing for spatial spillovers[16]. Finally, the model is specified as follows:

$$p_i = \alpha_0 + \lambda \sum_{j=1}^{n} w_{ij} p_j + \sum_{c=1}^{C} \beta_c x_{ci} + \sum_{q=1}^{Q} \gamma_q y_{qi} + \sum_{r=1}^{R} \delta_r z_{ri} + \sum_{s=1}^{S} \phi_s v_{si} + u_i \quad (2)$$

$$u_i = \rho \sum_{j=1}^{n} m_{ij} u_j + \varepsilon_i \quad (3)$$

where λ is the spatial autoregressive parameter, ρ the spatial error parameter, and w_{ij} and m_{ij} are the spatial weight matrices[17]. In modeling the price of each apartment as depending on a weighted average of the prices of other apartments, the model determines the outcomes simultaneously, which implies that the OLS estimator is not consistent (Anselin, 1988). This endogeneity due to the spatial lag requires the use of an instrument matrix.

As the error terms are not normally distributed, the Maximum Likelihood estimator (ML) is not relevant[18]. Moreover, the model residuals are affected by spatial correlation and heteroscedasticity. Heteroscedasticity is likely due to spatial heterogeneity, as the housing market is generally not uniform over space[19]. Despite the introduction of spatial submarket dummies to reduce spatial heterogeneity, there is still disturbance heteroscedasticity. We consequently use the GMM estimator proposed by Kelejian and Prucha (2010) for the spatial autoregressive parameter in the disturbance process, as this estimator allows for heteroskedastic error terms. The model is estimated in the first step by the Two Stage Least Square method (2SLS) using the instrument matrix. In the second step, the autoregressive parameter ρ is estimated using the GMM estimation based on the 2SLS residuals from the first step. To account for spatial correlation, the regression model is re-estimated in the third step by the 2SLS method, after applying a Cochrane-Orcutt type transformation to the model (for further details, see Kelejian and Prucha, 2010).

Results

The results of this model are reported in Table 3.

The parameter λ is positive and significant, indicating spatial autoregressive dependence in apartment prices. The parameter ρ is positive and significant, so that the unobserved components of the model are spatially linked. The spatial submarkets variables are globally significant[20].

The effects of apartments' intrinsic and contextual attributes

The role of intrinsic characteristics of dwellings in real-estate capitalization that we find in Nantes Métropole is globally consistent with other work on French data (Cavailhès, 2005; Bono *et al.*, 2007; Fritsch, 2007; Bureau & Glachant, 2010; Trannoy & Wasmer, 2013). Among these attributes, the surface area plays a major role. In order to investigate potential nonlinear relationships, we add the squared surface area to the surface area, and find a concave relationship between the latter and the price of the apartment. Such a result could indicate a saturation effect of buyer preferences when a dwelling surface area lies above a certain threshold. We emphasize that this threshold is located between 200 and 220 m² according to the year of transaction.

13. As LM-Error and LM-Lag were always significant, robust tests were used because both LM-Error and LM-Lag have power against the other alternative.
14. The average distance between each observation and its k-th nearest neighbor is 1.1 km in 2002 (60th nearest neighbor), 1.4 km in 2006 (100th nearest neighbor) and 1 km in 2008 (40th nearest neighbor).
15. The n × n spatial weight matrix is row standardized: each row sums to one.
16. The AIC and BIC criteria conclude that the inclusion of the spatial autoregressive and spatial error parameters improves the model fit in each year.
17. In our specification, $w_{ij} = m_{ij}$.
18. The quasi-ML estimator in the model proposed by Lee (2004) does not carry over to the case where the disturbances are heteroskedastic.
19. LeSage (1999) shows, for example, that the mean and variance of house prices change with the distance from the central business district.
20. We tested our models without the submarket dummies to see if they reduced the impact of other explanatory variables, notably accessibility and environmental quality variables. Our results proved to be similar.

Table 3
Estimation of the spatial hedonic price model for apartments in Nantes Métropole, 2002, 2006 and 2008

Variables	Model 2002	Model 2006	Model 2008
Surface area	0.0163** (0.0004)	0.0146** (0.0003)	0.0156** (0.0003)
Surface2	-0.0063** (0.0006)	-0.0056** (0.0004)	-0.0057** (0.0006)
Constr<1948	-0.2370** (0.0426)	-0.1194** (0.0289)	-0.1243** (0.0351)
Constr[1948-1969]	-0.2401** (0.0198)	-0.1769** (0.0150)	-0.2161** (0.0159)
Constr[1970-1980]	-0.2561** (0.0210)	-0.1548** (0.0149)	-0.2089** (0.0168)
Constr[1981-1991]	-0.1169** (0.0179)	-0.0747** (0.0157)	-0.1226** (0.0161)
Sale before completion	0.1489** (0.0190)	0.1755** (0.0134)	0.2053** (0.0175)
No parking space	-0.1629** (0.0559)	-0.0928** (0.0256)	-0.1623** (0.0292)
>One parking space	0.0388** (0.0117)	0.0366* (0.0143)	0.0115 (0.0153)
ZUS	-0.0568 (0.0436)	-0.0922** (0.0213)	0.0305 (0.0331)
Contiguous ZUS	-0.0237 (0.0179)	-0.0322** (0.0122)	-0.0194 (0.0179)
Median income	0.1414** (0.0480)	0.1010** (0.0313)	0.1869** (0.0446)
Private road	-0.0409** (0.0143)	-0.0258** (0.0087)	-0.0085 (0.0103)
Green spaces	0.0039** (0.0015)	-0.0004 (0.0009)	0.0004 (0.0014)
Distance centre	-0.0648** (0.0211)	-0.0367* (0.0156)	-0.0956** (0.0227)
Dist. railway station	0.0235+ (0.0127)	0.0122 (0.0102)	0.0174 (0.0185)
Distance to bus stop	0.0052 (0.0099)	-0.0096 (0.0066)	-0.0040 (0.0094)
Tram>500m	-0.0020 (0.0177)	0.0009 (0.0112)	-0.0127 (0.0137)
Max. noise	-0.0006 (0.0005)	-0.0013** (0.0004)	-0.0010* (0.0005)
Air pollution	0.0182 (0.0195)	0.0260+ (0.0150)	0.0087 (0.0168)
Temporal effects			
Second quarter	0.0271+ (0.0149)	0.0290** (0.0099)	-0.0101 (0.0118)
Third quarter	0.0425** (0.0129)	0.0448** (0.0103)	-0.0170 (0.0127)
Fourth quarter	0.0527** (0.0140)	0.0509** (0.0119)	-0.0254 (0.0128)
Spatial submarkets			
Submarket 2 *(HH)*	0.0711* (0.0338)	0.1041** (0.0209)	0.0309 (0.0294)
Submarket 3 *(LL)*	0.0308+ (0.0180)	-0.0087 (0.0115)	0.0254 (0.0167)
Submarket 4 *(LH)*	-0.1171** (0.0296)	-0.0959** (0.0254)	-0.1538** (0.0286)
Submarket 5 *(HL)*	0.1449** (0.0177)	0.1224** (0.0135)	0.0869** (0.0169)
Constant	6.0400** (0.7397)	6.9313** (0.9531)	6.9271** (1.3387)
Lambda	0.3803** (0.0671)	0.3566** (0.0788)	0.3163** (0.1108)
Rho	0.6481** (0.0652)	0.5671** (0.0983)	0.7699** (0.0644)
Observations	1,943	1,981	1,666

Note: ** Significant at 1%, * significant at 5% and + significant at 10%.
HH: The observed values of the transaction and its neighbors are high; *LL*: the values of the transaction and its neighbors are low. *LH*: the value of the transaction is low but those of its neighbors are high; *HL*: the value is high but those of its neighbors are low.
Coverage: 5,590 apartment transactions in the 24 communes of Nantes Métropole in 2002, 2006 and 2008 (respectively 1,943, 1,981 and 1,666 observations).
Sources: *Perval* 2002, 2006 and 2008; authors' estimations.

Several other intrinsic attributes also influence apartment prices in Nantes Métropole. Post-1991 buildings sell at higher prices than older ones. Buyers' perceptions of potentially worse apartments, with less efficient thermal and acoustic insulation than more recent ones, could lie behind this result[21]. In the same way, new apartments (sold before completion) also benefit from considerably higher prices. The number of parking spaces also significantly influences the price: apartments with no parking spaces sell at lower prices than apartments with one parking space, whereas apartments with two or more parking spaces sell at higher prices. Buyers would then seem to consider parking on a public road at home to be delicate.

Housing values are also usually determined by the geographical and socio-economic environment of the dwellings. Still, certain contextual attributes have no clear impact on the apartment prices in Nantes Métropole. Being located in a ZUS or an IRIS contiguous to a ZUS thus reduces the transaction prices in 2006, although these two variables are not significant in 2002 and 2008. This result can be interpreted as potentially showing the usefulness of urban-renewal programs in improving the image of these districts and their neighborhood. Conversely, in line with Bureau and Glachant (2010), median IRIS income is positively correlated with apartment prices.

The effects of location and accessibility variables

As the location and accessibility variables were constructed in the framework of the multidisciplinary research project, these attributes were expected to be more informative. Indeed accessibility variables, especially proximity to transport networks, often play a role in hedonic studies in Europe and elsewhere, as we highlighted in the Literature review section. Still these effects are not always significant; if they are, they may highlight either the expected accessibility effect yielded by the transport facility (inducing real-estate capitalization) or, conversely, a negative externality effect notably due to the higher noise levels endured (causing a drop in housing prices). Last, such effects remain dependent on the local context in the sense that, as we will see, the existing transport networks in the city may be considered more or less dense by the buyers. It thus seems important to confirm or refute the partial results of Fritsch concerning the tram influence in Nantes (2007). To this end, we discuss the results obtained through the construction of accessibility variables intended to complete the hierarchy of public transport networks: from above (commuter rail) and from below (the bus network).

In the first place, the proximity to Nantes city centre unsurprisingly plays a positive role. We verify that there is no evidence of a nonlinear effect between this distance and the price of the apartment. This linear relationship is both in line with theoretical (Fujita, 1989) and empirical literature: notably in Paris (Bureau & Glachant, 2010), and in Bordeaux city centre (Gaschet & Pouyanne, 2011).

Concerning the construction of the accessibility variables to public transport, we follow specific strategies according to the network. As bus stops can be found in the peripheral municipalities of Nantes Métropole, the variable "distance of the apartment from the nearest bus stop" can be introduced in a continuous form. Conversely, as the locations of tram stops are more correlated with the distance to the city centre (no tram stops outside the ring road), we choose to use a dummy variable ("Presence of a tram stop less than 500 meters away"). The threshold of 500 meters approximately reflects the median value of the distribution. Concerning non-urban public transport (commuter rail), it should be noted that only 12% of transactions are located less than one kilometer from the central railway station. These particular locations could be viewed as a premium by the buyers.

However, proximity to the closest railway station does not play the expected accessibility role, with not significant estimated coefficients. This may reflect the minor role played by the non-urban railway network in urban mobility in France. Moreover, in Nantes Métropole, this likely is due to the good accessibility to urban public transport, which is expected to provide a better service than commuter rail inside the conurbation, notably in terms of frequency and daily operating times.

The assumption of a greater interest of the apartment buyers towards the urban transport networks is however not verified: we find no significant influence of the bus and tram networks on apartment prices in Nantes Métropole

21. Unfortunately, no information was available on the state of the apartment at the time of transaction.

either. The estimated bus coefficients are insignificant in all three transaction years. However, this absence of valuation may simply be due to the high density of urban transport networks in the city in general, which makes immediate proximity to a bus stop superfluous from the buyer's point of view.

The four tramlines were established to help make radial trips to Nantes city centre using public transport. The three first lines were opened between 1985 and 2000. As the third line was extended to the North of Nantes in 2004 and the fourth line was opened in 2006 (the "busway" line as a Bus Rapid Transit), these trips to the city centre were made possible from various points of the ring road. However, in the same way as above, our results show that being located in a 500-m radius around a tram stop does not significantly affect apartment prices in Nantes Métropole, with coefficients never significant for any transaction year[22]. Unlike Fritsch (2007), we therefore cannot conclude, for apartment transactions in Nantes Métropole, for the existence of either an accessibility effect of the tram network, or a negative effect from being located too close to a tram stop (in particular given the noise expected). This result is in line with those of Travers *et al*. (2014), who show that the "busway" line has no significant impact on housing prices in the municipalities of Nantes Métropole crossed by this new line (Nantes, Vertou and Saint-Sébastien-sur-Loire).

Concerning the remaining location variables, we do not emphasize any clear influence on apartment prices either. In two distinct ways, being on a private road and benefiting from large green-space surface areas around the apartment can be considered as amenities. However, despite the expected quiet environment, location on a private road (which is the case for 30% of the observations) is actually associated with lower prices in 2002 and 2006; this is likely due to the difficulty of access when roads are narrow. Concerning green spaces, the existence of a surface area within 300 meters around the apartment is significant only in 2002. However, a positive influence of green spaces close by has been highlighted in a number of French cities: Paris (Bureau & Glachant, 2010) and Angers (Choumert & Travers, 2010). Our results here are more mixed insofar as green spaces do not significantly affect housing prices in 2006 and 2008, probably because Nantes, in recent years, has been one of the most active French cities with respect to green spaces and public expenditure per capita[23].

The effects of environmental quality variables

Households are expected to value an improvement in environmental quality in urban centres, where it is generally considered deficient. Moreover, like accessibility, these attributes can be modified by sustainable urban mobility plans (Ellison *et al.*, 2013). For these reasons, environmental quality variables (noise exposure and air pollution) were also constructed as part of the multidisciplinary research project, as potential factors of valorization or depreciation of the dwellings.

We retain in our models the noise variable that refers to the maximum noise level from roads and railways over a 24-hour period. Our results prove to be quite robust, as they are comparable whatever the noise variable introduced: day-time, evening or night-time; maximum, mean or minimum level. In the end, noise exposure reduces the price of apartments in 2006 and 2008[24]. For a noise exposure of 55 to 60 dB, our results suggest a lower price of 0.28% per additional decibel. This coefficient is lower than that in Boiteux's report (2001): the figures there are 0.4% for the same dB interval, and 1.1% for over 75dB. In a previous study, Le Boennec and Sari (2015) find a comparable effect of noise on house prices in Nantes Métropole (-0.23% per additional decibel), again a lower value than in Boiteux's report. Our result may be due to the quiet environment found in Nantes Métropole in general.

Concerning the potential influence of air quality on the price of apartments in Nantes Métropole, it should be noted that only about 15% of dwellings are on average above the annual Air Quality Guideline (AQG) of the WHO (2000, 2006). However, even for this subsample of apartments, we do not find any positive relationship between air quality and the price. This result is confirmed for the apartments with better air quality. This general absence of relationship could reflect that real-estate capitalization is better explained by subjective perceptions of environmental attributes rather than objective data, as shown in Chasco and Le Gallo (2013). The explanation is double. First, the largely invisible and

22. Other threshold distances were tested, without success.

23. In the 2017 ranking of the Observatory of Green cities, Nantes was second of the 50 most-populated French cities.

24. The estimated price of an apartment that exchanged hands in 2008 is thus €117,170 above 62dB, whereas it is €121,391 below this threshold.

intangible nature of air quality generally renders objective measures non influent, except in the case when the pollution is odorous or visible. Second, air pollution is seen as ephemeral, even though its effects on health are tangible (Le Boennec & Salladarré, 2017). Last, lower air quality is more difficult to perceive when average air quality is high.

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Our hedonic pricing analysis of apartment transactions in Nantes in 2002, 2006 and 2008 highlights the only moderate degree of real-estate capitalization with respect to accessibility to the city centre, air quality and noise reduction.

We confirm that housing prices in Nantes Métropole depend above all on the intrinsic attributes of the apartments and their socio-economic environment. In contrast, our results regarding accessibility are not particularly strong. In line with Travers *et al.* (2014), who find no real-estate capitalization for the "busway" line in Nantes Métropole, our results show no significant accessibility effect of urban and non-urban transport networks (bus, tram and train). Such an absence of a clear relationship between public transport and housing prices may be interpreted in two different ways. This may reflect sufficiently-good connections to the city centre from the buyer's point of view, regardless of the location of the apartment (given that the vast majority of apartments are located inside the ring road). Conversely, this may indicate the lack of buyers' interest in public transport in general, in that the corresponding modal share does not exceed 15% of total trips (as in comparable French *Métropoles*). Indeed, over 60% of public transport users are under 25 and so are probably not active in the housing market.

The effects of environmental quality are not obvious either. On the one hand, the noise from road and rail is perceived negatively: we emphasize that apartment prices fall with noise exposure, although the effect is only small in size. On the other hand, we show that the concentration of airborne pollutants does not reduce apartment prices, even for the most-exposed dwellings. The explanation may lie in the fact that individuals are generally more sensitive to noise than air pollution. Such an attitude is consistent with the environmental economics theory that takes air pollution as a negative externality that individuals do not take into account when they purchase on the housing market. Environmental and public health policies thus have a role to play. A contextual interpretation may be provided in addition: environmental quality is generally good in Nantes Métropole, so households are probably less sensitive through housing valuation. The method we use to elaborate the environmental quality variables may also play a role: different results could have been found through the use of observed noise and air pollution values, unfortunately not available, instead of the values calculated from traffic data.

Do these results finally make the case for voluntarist public policies in favor of public transport? The 2010 Grenelle 2 French Law advocates tax policies regarding real-estate capital gains from selling property with transport facilities close by. However, our results suggest that these polices may be useless if awareness policies towards transport users are not implemented at the same time: local authorities should thus continue to emphasize the individual and collective benefits in order to make larger groups of individuals aware of the use of public transport. This could be carried out jointly with improvements in the quality of service (including carpooling options when bus lines are not profitable) and consequent investments in mobility platforms (mobile apps) in order to facilitate daily trips for everyone.

As hedonic price models cannot take into account all of the elements that affect housing prices, our results should be treated with caution. First, access to street and road networks could not be examined as potential premiums, as these variables were not geo-referenced in the framework of the research project. There are in addition many other factors that play a role in the perceptions of the quality of the living environment, such as security, the quality of schools, job opportunities, and proximity to the sea or other unique natural resources. All of these factors may be reflected in the housing market; however, as our models explain over 80% of the variance in apartment prices, these remaining factors should only have a relatively minor role to play in Nantes. More generally, a permanently high demand-to-supply ratio reveals the lack of apartments on the market. In this case, certain apartment attributes may be regarded as secondary by buyers, as can be seen in Nantes Métropole and other attractive cities. □

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