



CONTRASTING EFFECTS OF AIR POLLUTION ASSESSMENT IN TWO AREAS OF THE QUITO METROPOLITAN DISTRICT, ECUADOR

EFFECTOS CONTRASTIVOS DE LA EVALUACIÓN DE LA CONTAMINACIÓN AMBIENTAL EN DOS ZONAS DEL DISTRITO METROPOLITANO DE QUITO, ECUADOR

Daniel Cornejo-Vásconez¹, Fabián Rodríguez-Espinosa^{*1,2}, Alejandra
Guasumba³ and Theofilos Toulkeridis²

¹ Facultad de Economía, Pontificia Universidad Católica del Ecuador, Quito, Ecuador.

² Departamento de Ciencias de la Tierra y Construcción, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador.

³ Departamento de Geografía, Pontificia Universidad Católica del Ecuador, Quito, Ecuador.

*Corresponding author: ffrodriguez3@espe.edu.ec

Article received on May 11th, 2020. Accepted, after review, on October 29th, 2021. Published on September 1st, 2022.

Abstract

One of the main factors of air contamination within urban areas is burning gasoline by cars, light trucks and motorcycles. Gasoline burning liberates pollution gases such as Nitrogen dioxide, Sulfur dioxide, Carbon monoxide, benzene, besides others. Among these, Nitrogen dioxide (NO_x) is the one that stands out for the people's awareness of such contamination. We used the Hedonic Price Method (HPM) in order to determine people's perception of air quality as a proxy and estimate the effect of gases on the housing market. We selected two areas of Quito Metropolitan District in order to evaluate contamination effects on properties. One with a higher concentration of gases located within the historic district of Quito. The other with better air quality called the Bellavista district. The results of three different models indicated that a reduction of 1 (μg/m³) of NO_x would increase an average of 4.54% of the housing market value, which it represents 2,032,326.24 USD in value for sample properties. A decrease of 5 μg/m³ will increase in 22.7% of properties value.

Keywords: Greenhouse gases, hedonic price, housing value, air contamination, Quito.

Resumen

Uno de los principales factores de contaminación del aire dentro de las zonas urbanas es la quema de gasolina por parte de autos, camiones ligeros y motocicletas. La quema de gasolina libera gases contaminantes como el dióxido de

nitrógeno, el dióxido de azufre, el monóxido de carbono y el benceno, entre otros. Entre ellos, el dióxido de nitrógeno (NO_x) es el que destaca por la concienciación de la gente sobre dicha contaminación. En esta investigación se utilizó el Método de los Precios Hedónicos (MPH) para determinar la percepción de la gente sobre la calidad del aire como indicador y estimar el efecto de los gases en el mercado inmobiliario. Se seleccionaron dos zonas del Distrito Metropolitano de Quito para evaluar los efectos de la contaminación en los inmuebles. Una con mayor concentración de gases ubicada dentro del casco histórico de Quito, y la otra con mejor calidad de aire conocida como el sector Bellavista. Los resultados de los tres modelos diferentes indicaron que una reducción de $1 \text{ } (\mu\text{g}/\text{m}^3)$ de NO_x aumentaría un promedio de 4,54% el valor del mercado inmobiliario, lo que representa un valor de USD 2.032.326,24 para las propiedades de la muestra. Una disminución de $5 \text{ } (\mu\text{g}/\text{m}^3)$ aumentaría en un 22,7% el valor de las propiedades.

Palabras clave: Gases de efecto invernadero, precio hedónico, valor de la vivienda, contaminación del aire, Quito.

Suggested citation: Cornejo-Vásquez, D., Rodríguez-Espinosa, F., Guasumba, A., and Toulkeridis, T. (2022). Contrasting effects of air pollution assessment in two areas of the Quito Metropolitan District, Ecuador. *La Granja: Revista de Ciencias de la Vida*. Vol. 36(2):98-112. <http://doi.org/10.17163/lgr.n36.2022.08>

Orcid IDs:

Daniel Cornejo-Vásquez: <http://orcid.org/0000-0001-5182-3793>
Fabián Rodríguez-Espinosa: <http://orcid.org/0000-0002-2754-1347>
Alejandra Guasumba: <http://orcid.org/0000-0001-6119-2454>
Theofilos Toulkeridis: <http://orcid.org/0000-0003-1903-7914>

1 Introduction

Clean air is considered as one of the most basic requirements of human health and well-being (World Health Organization, 2016). Its relative purity or contrarily its pollution may determine different social and economic problems (Panayotou, 2016; Gulia et al., 2015; Victor, 2017). An estimation of physical damages can be done by estimation visibility impacts, acid rain impacts, crop and other vegetation damages, property value impacts, corrosion and soiling impacts, recreation effects, and health effects. Poor air quality is associated with the incidence of short and long-term diseases, particularly neurologic and of the the respiratory system, as mentioned by several authors like Zivin and Shrader (2016); Calderón-Garcidueñas et al. (2016); Perera (2017).

Organization (WHO) estimated that in 2014, 82% of the population in developing countries may be subject to levels that tend to exceed minimum quality standards as stipulated in their guidelines on air-quality (World Health Organization, 2006, 2016). This issue has a greater incidence in large cities on all continents (Smith and Huang, 1993; Bayer et al., 2009; Kennedy et al., 2007). Nevertheless, the impact on health of air pollution is difficult to assess. Several studies have used the value of statistical life (VSL) as a method to estimate marginal reduction in the risk of premature death (Sanchez Martinez et al., 2018; World Bank, 2016; Franchini and Mannucci, 2015; World Health Organization, 2016). However, these studies required a complete data of premature deaths to estimate its potential cost. In this particular study, we did not consider the effects of pollution on health because we did not have access to premature deaths information due to such information is restricted to health centers and health governmental offices that do not facilitate it.

Instead, we estimate the impact of physical damages on the property value. Several studies have demonstrated that it also allows to affect the price of homes, impacting on the value of the private patrimony of citizens (Bajari et al., 2012; Cebula, 2009; Neupane and Gustavson, 2008; Égert and Mihaljek, 2007; Chau et al., 2006; Kiel, 2006; Jackson, 2001; Harrison Jr. and Rubinfeld, 1978; Rodriguez et al., 2017). These investigations have been based on the

classic study of Rosen (1974), who developed the theoretical basis of the hedonic model, and later on the studies of Freeman III (1974) as well as Harrison Jr. and Rubinfeld (1978) when performing empirical studies of the theory. These pioneering works determined the demand and benefits for clean air in urban areas. Air pollution is a problem originated of anthropogenic activities and has been directly related to the different particular and economic activities of citizens (Toulkeridis et al., 2020). This concern arises within the open urban spaces according to the intensity of the burning of fossil fuels either by industrial activity or by the use of vehicles (World Health Organization, 2016). Therefore, the reduction of pollution automatically allows citizens of any given city to breathe less contaminated or strictly better air (World Bank, 2016; World Health Organization, 2016), or improve the value of a property. This becomes an environmental service, whose monetary valuation enhances fundamentally as a guide to appropriate policy measures that protect health as well as the economic situation at a heritage level. Hereby, in a complementary way to the health benefits, the relative quality of the air affects the (de-) valorization of real estate due to the contamination levels of its location (Del Giudice et al., 2017; Saaty and De Paola, 2017).

In this sense, pollution represents a negative externality and the Hedonic Pricing method suits as a technique that allows the economic valuation of air quality as an environmental service. Consequently, it supports to infer the willingness to pay agents in order to receive better air quality from its impact on the real estate market. The underlying central assumption pursues individuals will pay a higher price for a house, apartment or office, which may be located in an area with less air pollution, compared to a property with similar characteristics in an area with higher contamination (Harrison Jr. and Rubinfeld, 1978; Echegaray-Aveiga et al., 2020; Robayo et al., 2020; Poma et al., 2021). With the support of the aforementioned methodology, the current study may estimate the economic value of the air quality in the city of Quito in central Ecuador, by contrasting the effects of air pollution in two exemplary areas such as Bellavista and the Historic District. This purpose will be based on their geographic location, geomorphological content, vehicle access, and house distribution, which may indicate different levels of average pollution (Toulkeridis et al.,

2016; Nugra et al., 2016; Guanochanga et al., 2018, 2019; Fuertes et al., 2019; Borja-Urbano et al., 2021).

1.1 The case study of the city of Quito

The Metropolitan District of Quito (DMQ), in central Ecuador (Figure 1) is a large city at a considerable altitude, where an evaluation of the particular air quality situation has not been conducted yet. Nowadays, the city of Quito has approximately three million inhabitants, being the most populated in the country. Despite this, it is the city with the highest general industrial activity in the country with a Gross Value Added (GVA) of 23.7 billion USD according to the Central Bank of Ecuador Regional Accounts (BCE, 2015). Simultaneously, the vehicle fleet has grown by 57% since 2012, placing the city above the national average (INEC, 2016), increasing the air contamination in the DMQ.

According to the Air Quality Report of the Secretary of Environment of Quito (SAQ) in the DMQ (SAQ, 2017), the main source of air pollution of the DMQ is the transport that uses diesel fuel and gasoline, worsened by vehicular congestion caused by private vehicles. Additionally, there is a severe impact of the use of bunker fuel and fuel oil by thermoelectric plants and other industries in specific areas of the DMQ. Such activities are responsible for the concentration of pollutant particles in the air, such as Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Sulfur Dioxide (SO_2) Particulate Matter (PM_{10}), $\text{PM}_{2.5}$, Ammonia (NH_3) or Benzene among others of lower amounts based on the Ecuadorian Standard of Air Quality (NECA). According to Baca (2014) main source of pollution is mobile sources such as private vehicles and public transportation, area sources of pollution such as waste disposal facilities are the second source of air pollution in the DMQ and in less degree stationary sources.

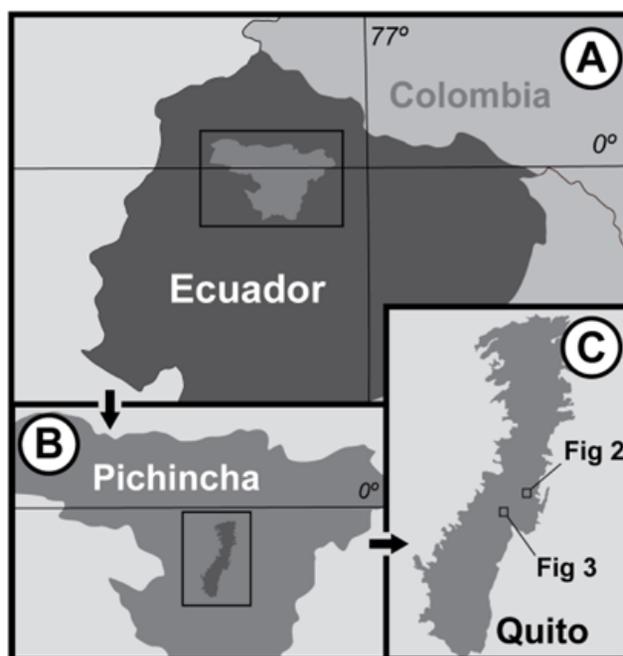


Figure 1. Study area.

Air quality is considered as an environmental service by The Economics of Ecosystems and Biodiversity Initiative (The Economics of Ecosystems and Biodiversity, 2013), and its economic or monetary valuation results, fundamental as guidance for policymakers in order to improve the health

of citizens. Reasonably and as complementary to health benefits, the relative air quality impact on real estate property value or devaluation of a property due to air contamination levels as a negative externality may demonstrate air quality economic value. The hedonic price method allowed to value

the impact of this externality estimating buyers' willingness to pay for a better air quality through the housing market. It is assumed that buyers would pay an additional value for properties located in areas with less contamination (Harrison Jr. and Rubinfeld, 1978).

The current study tries to estimate the air quality economic value of Quito by contrasting the impact of contamination in two areas, Bellavista and the Historic District, which represent two different levels of contamination. The choice of these two sectors seeks to capture the effect of air purification by nearby forest ecosystems. Bellavista's neighborhood borders the Metropolitan Park of Quito, which is a forested recreational park, where pollution degrees certainly are relatively low. The Historic District of Quito represents some spatial characteristics such as narrow streets, constant traffic flow and traffic jams, public transport flow close to industrial establishment areas besides other air contaminating issues that allow an understanding that the environmental pollution estimates exceed the city average for this area.

Due to Quito's Metropolitan Atmospheric Monitoring Network (REMMAQ), which determines the air quality of the city, we have been able to quantify the air quality of both focused areas. The REMMAQ appraised air quality since 2003 with some 39 stations throughout the urban area, surrounding valleys as well as regional and street level (SAQ, 2017). It has been expected to allow transparency about the economic fees assumed by the citizens of Quito on the price of their homes. Therefore, we consider that the results of the current study may serve to present the benefits that they may represent for the city and, specifically to the heritage of the people of Quito. Additionally, the adoption of policy measures may improve air quality and protect the ecosystem that supports its purification.

Air purification is an environmental service provided by ecosystems. Within the classification of the Economics of Ecosystems and Biodiversity Initiative TEEB, which divides environmental goods and services by categories (supply, regulation, life support, and culture), air quality has been conceived as an ecosystem regulation service (The Economics of Ecosystems and Biodiversity, 2013). Meanwhile, in Ecuador, the NECA establishes polluted air as the

presence of substances in the atmosphere, resulting from human activities or natural processes, present in sufficient concentration, for a sufficient time and under circumstances such as to interfere with comfort, the health or well-being of human beings or the environment (Ministerio del Ambiente del Ecuador, 2011). For NECA and the SAQ, the most representative substances in the atmosphere are mainly SO₂, CO, NO₂, O₃ and benzene and in lesser quantity M₁₀, PM_{2.5}, Cadmium and Inorganic Mercury. The review of preliminary studies on the assessment of air quality indicates a particular interest in the NO₂ variable as a proxy for contamination (Smith and Huang, 1993), while others suggest that the pollution variables are strongly correlated. If this is the case then it is recommended to use NO₂ as a proxy, as it is linked to the most visual pollution, being the product of combustion processes (Harrison Jr. and Rubinfeld, 1978).

1.2 Context of the Hedonic Pricing Method

The Hedonic Pricing Method (HPM) identifies the environmental service flow as characteristics that describe in a particular way a market good, typically being real estate (Hanley and Barbier, 2009). The theoretical validity of the method has been based on the Theory of Value from the proposed approach (Rosen, 1974; Lancaster, 1979), which indicates that a unit of good or service (h_i) within the group of goods and services of the same market has been to be described by a vector of its characteristics, being named as Z (Hanley and Barbier, 2009). In this sense, the price of this unit of good or service ($p(h_i)$) may be seen as a function of the characteristics. Formally, the relationship is defined as follows:

$$p(h_i) = f(Z_i) \quad (1)$$

Already in practice, based on the proposed definition of the HPM, it has been established that the value of a house belonging to the set of houses of the universe of interest depends on two main conditions. The first is a vector of characteristics (number of rooms, square footage, neighborhood, criminality, etc.), while the second is a vector of environmental variables such as proximity to parks. By differentiating the price for the quantity of any characteristic, the implicit price is obtained in relative terms. The implicit price documents the average willingness to pay given a certain quantity or quality of one of its characteristics (Hanley and Barbier,

2009).

If one seeks to adequately identify the magnitude of the effect of environmental good and service on the market price of the real estate, the theory allows the characteristics to be disaggregated and all those with the exception of the environmental variable to be kept constant; i.e., where the *ceteris paribus* condition applies (Schiffer, 1991; Boumans and Morgan, 2001). The logic underlying the concept of implicit price establishes that agents look forward to maximizing their utility, so they adapt their purchases to the condition of rationality and their perception of good qualities, leading to the point when the marginal rate of substitution (MRS) equals the implicit price of a certain characteristic (Hanley and Barbier, 2009).

This argument is important as it validates two fundamental assumptions: 1) the agents are in the ability to reflect and consider factors such as air pollution and other characteristics of a house when having to choose; 2) It is allowed to establish the principle that agents make an offer “on the margin”. This implies that the money they are willing to pay is equal to the benefit generated by the set of characteristics of the house. In fact, this is a necessary condition for the existence of exchange. In this context, it is intuitive to think that the price of a house reflects, in part, the marginal willingness to pay for better air quality as a desirable feature.

1.3 Hedonic price function for the case of air quality

Here we intend to define the theoretical functional form between the price of the real estate and the environmental variable of interest, specifically the quality of the air. In addition, the relevant explanatory variables are proposed. A hedonic price function may be estimated by establishing the relationships between the price of the property and its particular characteristics:

$$p_i = f(CS_i, CN_i, CE_i + \varepsilon_i) \quad (2)$$

Where, following the categorization of Égert and Mihaljek (2007) and Hanley and Barbier (2009):

p_i = property price i.

CS_i = characteristics of the site (number of rooms,

no bathrooms, surface, no garages, antiquity and green areas).

CN_i = characteristics of the neighborhood (crime and distance to the nearest park).

CE_i = environmental characteristics (in this case, contamination in the location zone is of interest).

ε_i = error term.

The proposed hedonic price function allows obtaining the implicit price. Hereby, the marginal change in the price of the property associated with the marginal change of any of the proposed characteristics may be obtained. Regarding the relationship of interest between price p_i and air pollution, it is expected that it does not follow a linear pattern. Following the argument of Rosen (1974) air quality is desirable as it is directly related to the price of housing but at a decreasing rate. Therefore, it is expected that $\frac{\partial p_i}{\partial CE_i} > 0$, but $\frac{\partial^2 p_i}{\partial CE_i^2} < 0$: the marginal cost of air quality, its implicit price, falls while the level of air quality increases. This appreciation is intuitive. When there are low levels of contamination, people are expected to value proportionally less such attribute compared to a scenario with severe contamination problems.

2 Methodological Procedure

The current study considers two zones whose levels of contamination differ substantively. The first zone is the Historic District of Quito (HDQ) (Figure 2) and the second zone is Bellavista in the North Center of the city. It is fundamental to consider that a criterion of choice of the Bellavista zone is its location that circuits the extreme south-west of the Metropolitan Park of Quito (Figure 3), which allows continuous processes of air purification. Based on the limits of Figure 2, the following geographical map has been constructed according to the information of the Quito Open Government (GAQ). It is interesting to compare the geographical map of the HDQ (Figure 3) with that presented with the Bellavista zone (Figure 2). It results that there is no greater presence of park-like green areas in the Historic District. In addition, there is a higher density of housing construction. Based on these results according to a geographical division of the chosen zones, the following information matrix of the sample may be defined according to the information of the amount (N) of houses (Table 1).



Figure 2. Geographical map of the Bellavista area.

Table 1. Matrix of the number of housing for the sample.

Zone	No. Properties (N=)	Confidence level (%)	Error range (%)	Sample size
Bellavista	3.056	95 %	5 %	342
Historic Center	15.456	95 %	5 %	375

The results of the sample size are obtained based on the following calculation method:

$$n = \frac{\frac{z^2 * \sigma^2}{e^2}}{1 + \left(\frac{z^2 * \sigma^2}{e^2 N}\right)} \quad (3)$$

Where,

e = error range (= 5%)

z = score (at a 95% level of significance)

N = population size

In the current study, a focal sample has been taken for reasons of information availability. The total

sample has a total of $n = 149$ observations, of which 80 correspond to the Historical District and 69 to the Bellavista area. The sample needs to include information on the value of the real estate and air pollution in the area where it is located. Additionally, it requires to collect data on other determinants of the price of the property that have been considered significant as control variables. Table 2 presents and defines the variables related to pollution levels in the HDQ or Bellavista, and those with additional control characteristics that potentially affect the price. Additionally, the information source for each variable is listed.

2.1 The Hedonic Pricing Method

2.1.1 Hedonic Price Model (HPM)

The hedonic price model (HPM) has been defined further below. Two basic HPM's are presented: I and II, considering the theoretical reflections presented in the previous sections. The HPM I demonstrates a linear evolution between the evolution of environmental variables and the price of housing. The

difference between model II and I is the application of the assumption of the relationship to decreasing rates between the price of a property and environmental quality in the real estate market. In this sense, an exponential correction factor is applied. The transformation of the variable rooms, surface, and age are also considered, elevating them to the square in both zones for the general model II. Models are obtained with or without the application of the

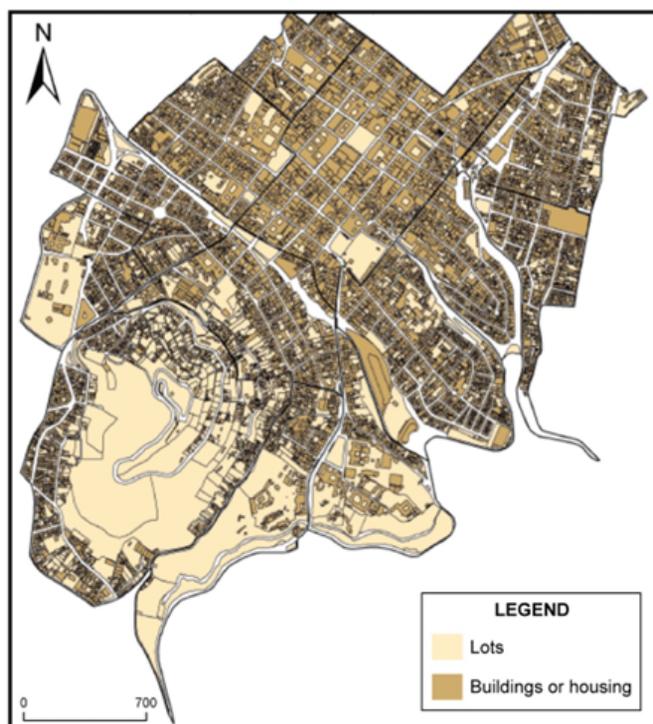


Figure 3. Geographical map of the Historical Center.

Table 2. Matrix of variables of the hedonic model. Sources: (a) Plusvalia.com, (b) Vive1.com, (c) OLX.com, (d) Secretaria de Ambiente del DMQ, (e) Fiscalia General del Estado

Concept	Variable	Definition	Unit	Source
Price	Market price	Market price of real estate (at the study date)	USD	a, b, c
Price m^2	Price m^2	Price m^2 of the real estate (at the study date)	USD/ m^2	a, b, c
Contamination	SO_2	Average annual concentration (= year 2016) of zoned sulfur dioxide	μm^3	d
Contamination	CO	Average annual concentration (= year 2016) of Zoned Carbon Monoxide	mg/m^3	d
Contamination	NO_2	Annual average concentration (= year 2016) of zoned Nitrogen Dioxide	μm^3	d
Contamination	O_3	Average annual concentration (= year 2006) of zoned ozone	μm^3	d
Contamination	Benzene	Average annual concentration (= year 2016) of zoned Benzene	μm^3	d
Rooms	No. of rooms	Number of rooms available	room	a, b, c
Bathroom	No. of bathrooms	Number of bathrooms available	bathrooms	a, b, c
Surface	Surface m^2	Surface extension	m^2	a, b, c
Garage	No. of garages	Number of own garages available	posts	a, b, c
Antiquity	Years of antiquaty	Number of years since the construction of the property	years	a, b, c
Green areas	Green areas	Availability of green areas such as gardens, green terraces, etc	0=no 1=yes	a, b, c
Crime	Criminality	Zoned sum of complaints of crimes against people and private property year 2016	complain	e

natural logarithm in the dependent variable. In this sense, Log-Log (elasticities) and Semi-Log (semi-elasticity) models are obtained, which also provides information of interest in this study. In general, the models are defined as follows:

Definition HPM I:

$$\ln(p_i) = \beta_0 + \beta_j \sum_{j=1} \ln(\text{contamination}_i^j) + \beta_k \sum_{k=5} \ln(\text{characteristics}_i^k) + \epsilon_i \tag{4}$$

Definición del MPH II:

$$\ln(p_i) = \beta_0 + \beta_j \sum_{j=1} \ln(\text{contamination}_i^j) + \beta_k \sum_{k=5} \ln(\text{characteristics}_i^k) + \beta_l \sum_{l=13} \ln\left[\left(\text{contamination}_i^l\right)^{0.5}\right] + \beta_{19} \text{rooms}_i^2 + \varepsilon_i \quad (5)$$

Where,

$\ln(p_i)$ = property price i

$\ln(\text{contamination}_i^j)$ = natural logarithm of the variable $j = 1 \dots 5$, of the set of pollution variables: {SO₂, CO₂, NO₂, O₃ and Benzene }

$\ln(\text{contamination}_i^l)^{0.5}$ = natural logarithm of the variable $l = 6 \dots 10$, of the set of variables of the square root of contamination: {SO₂^{0.5}, CO₂^{0.5}, NO₂^{0.5}, O₃^{0.5} and Benzene^{0.5} }

$\ln(\text{characteristics}_i^k)$ = natural logarithm of the variable $k = 11 \dots 18$, of the set of characteristic variables of the property: {rooms, ban, sup, garag, antiq, green areas and crime }

rooms_i^2 = number of rooms squared

ε_i = error term

3 Results and discussion

Air pollution between the Historic District of Quito and Bellavista differs when considering pollution variables resulting from the anthropogenic activities. Below are the results of the measurements of the concentration SO₂, CO, NO₂, O₃ and Benzene (Figure 4).

The results indicate that for all pollutants, the HDQ maintains lower levels of air quality compared to Bellavista. This corroborates the assertion about the existence of higher levels of pollution related to the result mainly of combustion processes (CO, NO₂, SO₂ and Benzene), and, indirectly, reflected in higher levels of O₃ between both zones. On the side of housing prices and price per square meter, the following information is obtained in the housing focus group.

The results of other house features were as anticipated. Variables such as construction area, parcel size, number of bedrooms, number of bathrooms,

house's age, and presence of a garden were significant at 99%. Among neighborhood characteristics, only garage was significant at 95%, while green areas were insignificant. We selected all significant variables with the environmental variables and ran again the final regression model.

The average price of the Bellavista area exceeds that of the Historic District in USD 47,267 (Figure 5). The cases of properties on the average in the Historic District are reduced even though in this zone the most expensive property of the sample is offered with a price of USD 1,480,000, being almost USD 900,000 higher than the most expensive property in Bellavista. When this information is complemented with respect to the minimum prices obtained, it is concluded that there is greater variability in the price sample in the case of the Historic Center versus Bellavista. A further way to have a more accurate understanding of the real estate market in both sectors is by evaluating its price per square meter.

Figure 6 illustrates that the real estate market in the Bellavista area is more expensive compared to the Historic Center. Hereby, the average square meter is almost three times larger. This occurs even considering the maximum or minimum price per square meter. In general, the Bellavista area is more attractive from the point of the valuation that is yielded to the real estate offered there. This turns out to be a positive result based on the objectives of the current study, as there are clear differences between the Historic District and Bellavista regarding per square meter housing price.

In order to obtain the results of the empirical models of the hedonic price function, the average annual concentration of milligrams per cubic meter of NO₂ has been taken into consideration, since the pollution variables are highly correlated, avoiding multicollinearity issues. An intuitive reason for this problem is the close relationship among contamination sources, such as combustion processes of CO, NO₂, SO₂ and Benzene. A potential solution might be seen in the extension to further study areas, giving a greater variability to pollution measures, as stated as a particular case of this study. However, we found the most optimal functional form that allows the goodness of fit and greater possible significance for what different modeling proposals are composed of.

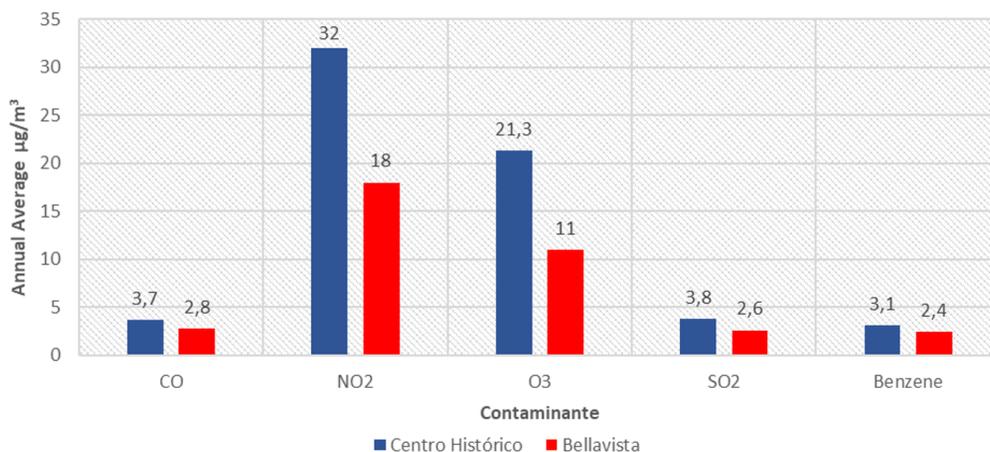


Figure 4. Comparison of pollutants by study area.

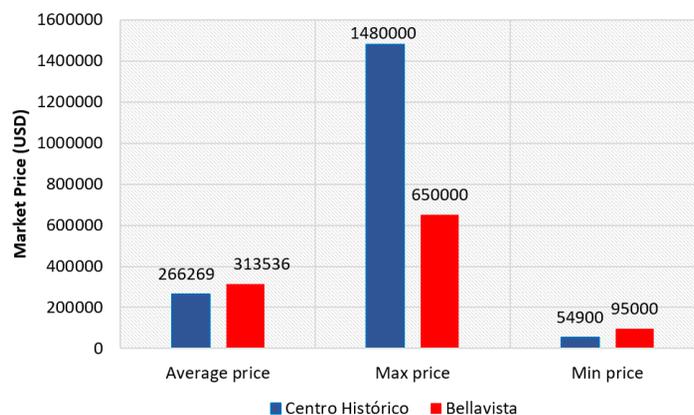


Figure 5. Comparison of housing market price according to study area. Adapted from Real estate websites.

In this sense, the results of the models in the semi-log version fit these specifications in a better way. The models that considered the relationship at decreasing rates between NO_2 and housing prices indicated a lack of improvement in the specification of the model. The estimation of adequate exponential value is more appropriate when studying a greater number of zones. Therefore, this may explain not giving a significant contribution to the explanation of the model despite having a theoretical validation. The models are corrected by heteroscedasticity. Particularly some variables such as the price per square meter (m^2) or housing age, for example, documented this issue. The results of the modeling in Table 3 are presented below.

We obtained high levels of R^2 values (91%), which have been similar to those yielded in Cebula (2009) of about $R^2 = 87\%$, Chau et al. (2006) $R^2 = 87\%$, and Jackson (2001) with $R^2 = 81\%$, indicating that the variables in the equation manage to explain to a considerable extent the variation of the housing price in the sample research. The variable NO_2 has a negative sign and turns out to be highly significant, even at a 99% confidence level in the three proposed models. Additionally, considering Model III, it decreases by $1 \mu gm^{-3}$ in the average annual concentration of NO_2 increase with the average price of homes by 4.54%. With such data, we have been able to assess the quality of the air as documented in Table 4, while considering the results of Model III.

Table 3. Results of Models I, II and III. Statistics t are in parentheses; *Exceeds 95% confidence level ($t > 1,96$); **Exceeds 99% confidence level ($t > 2,58$).

Variable	Model I	Model II	Model III
Dependent	Log (pm)	Log (pm)	Log (pm)
Constant	8.99 (9.72)	6.30 (12.02)	1.217 (0.44)
Log (Price (m2))	0.5288 (5.81)**	0.8389 (15.26)**	2.44 (2.84)**
Log (Price (m2)) ²			-0.1227 (-1.87)
Room	0.0852 (3.86)**	0.0694 (4.05)**	0.0677 (4.00)**
Room ²	-0.0029 (-5.17)**	-0.0022 (-4.64)**	-0.00213 (-4.54)**
Bathrooms	0.0530 (3.28)**	-0.0106 (-0.88)	-0.011 (-0.96)
Garage	0.0394 (2.25)*	0.0106 (0.85)	0.008 (0.67)
Surface	0.0012 (7.71)**	0.0039 (11.87)**	0.0039 (11.86)**
Surface ²		-1.35e-06 (-6.05)**	-1.32e-06 (-6.04)**
Antiquity	0.0045 (2.76)**	0.0076 (3.45)**	0.0063 (2.87)**
Antiquity ²		-0.00005 (-2.58)**	-0.00004 (-2.38)*
Green areas	0.9188 (1.40)	0.0338 (0.71)	0.0336 (0.44)
NO ₂	-0.0546 (-3.79)**	-0.0430 (-4.99)**	-0.0454 (-5.08)**
R ²	0.77	0.90	0.91

The estimates demonstrated that a decrease in the annual average of one milligram per cubic meter of NO_2 increases the price of housing by 4.5%. Likewise, a decrease of five milligrams per cubic meter of NO_2 increases by 22.7% the price of the homes of the research sample. In the first case, there is an increase in equity of 2,032,326.24 USD considering the 148 homes in the study area. In the second case, the equity increases, in aggregate terms, by 10,161,632.22 USD. The average price of the 148 homes increases between 13,731.93 and 68,659.67 USD,

as air pollution decreases between one and five milligrams per cubic meter of NO_2 . Obviously, a decrease of more than five ($\mu g m^{-3}$) of NO_2 would result in greater economic benefits. Thus, according to the reduction in the average annual levels of milligrams per cubic meter of NO_2 , owners will benefit from an improved value of their properties, and therefore, their assets. Ultimately, their economic situation improves due to the relative quality of the air in the area where the real estate is located.

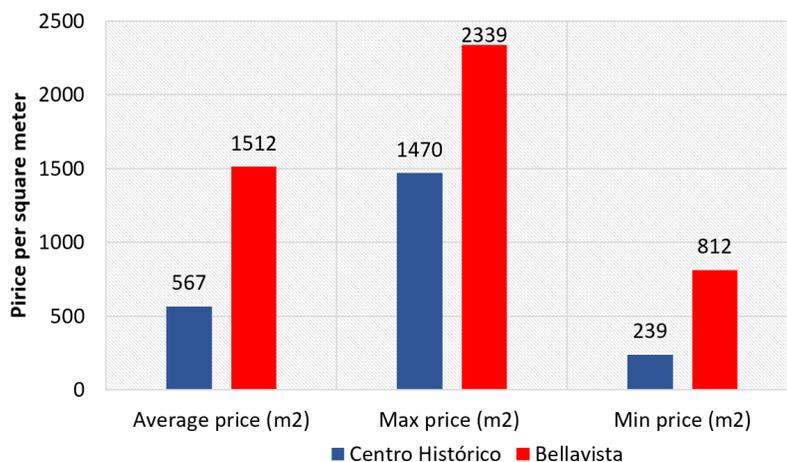


Figure 6. Price comparison m² of homes according to study area. Source: Real estate websites.

Table 4. Air Quality Assessment.

Variations				Focal sample		
Δ ⁻ (NO ₂) (μm/m ³)	Δ ⁺ (Price) (%)	Average price (USD)	Amount households (n)	Δ Heritage (USD)	Δ Average price (USD)	Difference of average prices (USD)
1	4.5%	302 465.51	148	2'032 326.24	316 197.44	13 731.93
2	9.1%	302 465.51	148	4'064 652.49	329 929.38	27 463.87
3	13.6%	302 465.51	148	6'096 978.73	343 661.31	41 195.80
4	18.2%	302 465.51	148	8'129 304.98	357 393.24	54 927.74
5	22.7%	302 465.51	148	10'161 631.22	371 125.18	68 659.67

4 Conclusions

The two different studied zones of the city of Quito, are directly affected (being understood as a negative externality) by different economic activities that generate pollution. Our results demonstrate that NO₂ (32 μgm⁻³) has the highest value among city pollutants. There is a significant difference between the Historic District and Bellavista, being 32 μgm⁻³, and 23 μgm⁻³, respectively. These levels of contamination have a direct effect on real estate price as it has been indicated. Differences in housing prices have been partially due to the varying levels of contamination between both zones.

Econometric models stated that a decrease in the annual average of one milligram per m³ of NO₂ increases the price of housing by 4.5%, meaning an increase in equity of 2,032,326.24 USD. The average price of the 148 homes increases of about 13,731.93

USD if air pollution declines in one milligram per cubic meter of NO₂. Obviously, a higher pollutant reduction will result in higher economic benefits.

These results may help to establish policies that intend to improve air quality. Policies such as promoting green areas in sites with high levels of pollution may correct the unfair penalties in owners' properties. Additionally, the obtained results indicate the importance of maintaining forested areas that play an important role in purifying the air, allowing people to benefit directly from qualitatively adequate air.

The current study considers a focal sample and this leads to limitations when inferring the results at population levels. However, the R² (0.91) is very high, allowing to generalize our results and justify more extensive research in the DMQ regarding air

pollution and its effects on property. In addition, the study concentrated only on the NO_2 pollutant, thus it is necessary to measure the other 3 pollutants.

References

- Baca, J. (2014). Informe final inventario de emisiones de contaminantes criterio, dmq 2011. Technical report, Secretaría de Ambiente, Distrito Metropolitano de Quito.
- Bajari, P., Fruehwirth, J., and Timmins, C. (2012). A rational expectations approach to hedonic price regressions with time-varying unobserved product attributes: The price of pollution. *American Economic Review*, 102(5):1898–1926. Online: <https://bit.ly/38l8LkY>.
- Bayer, P., Keohane, N., and Timmins, C. (2009). Migration and hedonic valuation: The case of air quality. *Journal of Environmental Economics and Management*, 58(1):1–14. Online: <https://bit.ly/3kgGRJz>.
- BCE (2015). Cuentas nacionales regionales. techreport, Banco Central del Ecuador, Quito, Ecuador. Online: <https://www.bce.fin.ec/index.php/component/k2/item/293-cuentas-provinciales/>.
- Borja-Urbano, S., Rodríguez-Espinosa, F., Luna-Ludeña, M., and Toulkeridis, T. (2021). Valuing the impact of air pollution in urban residence using hedonic pricing and geospatial analysis, evidence from Quito, Ecuador. *Air, Soil and Water Research*, 14:11–26. Online: <https://bit.ly/3ESFavG>.
- Boumans, M. and Morgan, M. (2001). Ceteris paribus conditions: materiality and the application of economic theories. *Journal of Economic Methodology*, 8(1):11–26.
- Calderón-Garcidueñas, L., Leray, E., Heydarpour, P., Torres-Jardón, R., and Reis, J. (2016). Air pollution, a rising environmental risk factor for cognition, neuroinflammation and neurodegeneration: The clinical impact on children and beyond. *Revue neurologique*, 172(1):69–80. Online: <https://bit.ly/399dJBL>.
- Cebula, R. (2009). The hedonic pricing model applied to the housing market of the city of Savannah and its Savannah historic landmark district. *Review of Regional Studies*, 39(1):9–22. Online: <https://bit.ly/38kXkd8>.
- Chau, K., Wong, S., Chan, A., and Lam, S. (2006). How do people price air quality: empirical evidence from Hong Kong. In *Presented at the 12th Annual Conference of the Pacific Rim Real Estate Society, Auckland, New Zealand*. The University of Auckland Business School.
- Del Giudice, V., De Paola, P., Manganello, B., and Forte, F. (2017). The monetary valuation of environmental externalities through the analysis of real estate prices. *Sustainability*, 9(2):1–16. Online: <https://bit.ly/3vGd2aM>.
- Echegaray-Aveiga, R., Rodríguez-Espinosa, F., Toulkeridis, T., and Echegaray-Aveiga, R. (2020). Possible effects of potential lahars from Cotopaxi volcano on housing market prices. *Journal of Applied Volcanology*, 9(1):1–11. Online: <https://bit.ly/3xZeoA2>.
- Égert, B. and Mihaljek, D. (2007). Determinants of house prices in central and eastern Europe. techreport, William Davidson Institute Working Paper Number 894.
- Franchini, M. and Mannucci, P. (2015). Impact on human health of climate changes. *European Journal of Internal Medicine*, 26(1):1–5.
- Freeman III, M. (1974). On estimating air pollution control benefits from land value studies. *Journal of environmental economics and management*, 1(1):74–83. Online: <https://bit.ly/3rOGU3A>.
- Fuertes, W., Cadena, A., Torres, J., Benítez, D., Tapia, F., and Toulkeridis, T. (2019). Data analytics on real-time air pollution monitoring system derived from a wireless sensor network. In *International Conference on Information Technology Systems*, page 57. Springer.
- Guanochanga, B., Cachipuendo, R., Fuertes, W., Benítez, D., Toulkeridis, T., Torres, J., Villacís, C., Tapia, F., and Meneses, F. (2018). Towards a real-time air pollution monitoring systems implemented using wireless sensor networks: Preliminary results. In *2018 IEEE Colombian Conference on Communications and Computing, COLCOM 2018 – Proceedings*. IEEE.

- Guanochanga, B., Cachipuendo, R., Fuertes, W., Salvador, S., Benítez, D., Toulkeridis, T., Torres, J., Villacís, C., Tapia, F., and Meneses, F. (2019). Real-time air pollution monitoring systems using wireless sensor networks connected in a cloud-computing, wrapped up web services. In *Proceedings of the Future Technologies Conference (FTC) 2018*, pages 171–184. Springer.
- Gulia, S., Nagendra, S., Khare, M., and Khanna, I. (2015). Urban air quality management-a review. *Atmospheric Pollution Research*, 6(2):286–304. Online:https://bit.ly/3xQajy6.
- Hanley, N. and Barbier, E. (2009). *Pricing Nature: cost-benefit analysis and environmental policy*. Edward Elgar Publishing.
- Harrison Jr., D. and Rubinfeld, D. (1978). Hedonic housing prices and the demand for clean air. *Journal of environmental economics and management*, 5(1):81–102. Online:https://bit.ly/3vArWPS.
- INEC (2016). El parque automotor de Ecuador creció 57% en cinco años. INEC. Online:https://bit.ly/3Oy4KdN.
- Jackson, T. (2001). The effects of environmental contamination on real estate: A literature review. *European Journal of Internal Medicine*, 9(2):94–116.
- Kennedy, C., Cuddihy, J., and Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of industrial ecology*, 11(2):43–59. Online:https://bit.ly/36OqHUU.
- Kiel, K. (2006). *Environmental Valuation: Interregional and Intraregional Perspectives*, chapter Environmental contamination and house values, pages 121–146. Ashgate: Aldershot.
- Lancaster, T. (1979). Econometric methods for the duration of unemployment. *Econometrica*, 47(4):939–956. Online:https://bit.ly/37v4qfd.
- Ministerio del Ambiente del Ecuador (2011). Normativa ecuatoriana de calidad del aire (neca), libro vi anexo 4. techreport, Ministerio del Ambiente del Ecuador, Quito, Ecuador.
- Neupane, A. and Gustavson, K. (2008). Urban property values and contaminated sites: A hedonic analysis of sydney, nova scotia. *Journal of Environmental Management*, 88(4):1212–1220. Online:https://bit.ly/3veAH34.
- Nugra, H., Abad, A., Fuertes, W., Galarraga, F., Aules, H., Villacis, C., and Toulkeridis, T. (2016). A low-cost iot application for the urban traffic of vehicles, based on wireless sensors using gsm technology. In *IEEE/ACM 20th International Symposium on IEEE, Distributed Simulation and Real-Time Applications DS-RT*, pages 161–169. IEEE.
- Panayotou, T. (2016). *The environment in anthropology (Second Edition): A Reader in Ecology, Culture, and Sustainable Living*, chapter Economic growth and the environment, pages 140–148. New York Press.
- Perera, F. (2017). Multiple threats to child health from fossil fuel combustion: impacts of air pollution and climate change. *Environmental health perspectives*, 125(2):141–148. Online:https://bit.ly/3vdf6rK.
- Poma, P., Usca, M., Polanco, M., Toulkeridis, T., and Mestanza-Ramón, C. (2021). Estimation of biogas generated in two landfills in south-central ecuador. *Atmosphere*, 12(10):1365. Online:https://bit.ly/3kgxKIW.
- Robayo, N., Llorca, J., and Toulkeridis, T. (2020). Population, territorial and economic analysis of a potential volcanic disaster in the city of latakunga, central ecuador based on gis techniques – implications and potential solutions. In *IEEE/ACM 20th International Symposium on IEEE, Distributed Simulation and Real-Time Applications DS-RT*, pages 549–563. Springer, Cham.
- Rodriguez, F., Toulkeridis, T., Sandoval, W., Padilla, O., and Mato, F. (2017). Economic risk assessment of cotopaxi volcano, ecuador, in case of a future lahar emplacement. *Natural Hazards*, 85(1):605–618. Online:https://bit.ly/3xV2oQm.
- Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. *Journal of political economy*, 82(1):34–55. Online:https://bit.ly/3EVQLdh.
- Saaty, T. and De Paola, P. (2017). Rethinking design and urban planning for the cities of the future. *Buildings*, 7(3):76. Online:https://bit.ly/3xUHrM.
- Sanchez Martinez, G., Spadaro, J., Chapizanis, D., Kendrovski, V., Kochubovski, M., and Mudu, P. (2018). Health impacts and economic costs of

- air pollution in the metropolitan area of skopje. *International Journal of Environmental Research and Public Health*, 15(4):626. Online:<https://bit.ly/39CE3o7>.
- SAQ (2017). Informe de calidad de aire 2016 del distrito metropolitano de quito. techreport, Secretaria de Ambiente del DMQ, Quito, Ecuador.
- Schiffer, S. (1991). Ceteris paribus laws. *Mind*, 100(1):1–17. Online:<https://bit.ly/3ELt33r>.
- Smith, V. K. and Huang, J. (1993). Hedonic models and air pollution: twenty-five years and counting. *Environmental and Resource Economics*, 3(4):381–394. Online:<https://bit.ly/39gxZSd>.
- The Economics of Ecosystems and Biodiversity (2013). Guidance Manual for TEEB Country Studies. Version 1.0. INEC. Online:<https://bit.ly/3Mub1oW>.
- Toulkeridis, T., Rodríguez, F., Arias Jiménez, N., Baile, D., Martínez, R., Addison, A., Carreón Freyre, D., Mato, F., and Díaz Perez, C. (2016). Causes and consequences of the sinkhole at el trébol of quito, ecuador-implications for economic damage and risk assessment. *Natural Hazards and Earth System Sciences*, 16(9):2031–2041. Online:<https://bit.ly/3EQIveo>.
- Toulkeridis, T., Tamayo, E., Simón-Baile, D., Merizalde-Mora, M., Reyes-Yunga, D., Viera-Torres, M., and Heredia, M. (2020). Climate change according to ecuadorian academics-perceptions versus facts. *La Granja*, 31(1):21–46. Online:<https://bit.ly/37LP8CT>.
- Victor, P. A. (2017). *Taylor y Francis Group LLC*. Secretaria de Ambiente del Distrito Metropolitano de Quito.
- World Bank (2016). The cost of air pollution: Strengthening the economic case for action. techreport, World Bank and Institute for Health Metrics and Evaluation.
- World Health Organization (2006). Air quality guidelines: global update 2005. techreport, WHO Regional Office for Europe publications. 496 pp, Druckpartner Moser, Germany.
- World Health Organization (2016). Ambient air pollution: a global assessment of exposure and burden of disease. techreport, WHO Document Production Services. 121 pp, Geneva, Switzerland.
- Zivin, J. and Shrader, J. (2016). Temperature extremes, health, and human capital. *The Future of Children*, 26(1):31–50. Online:<https://bit.ly/3EPF0oT>.