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The effects of the bus rapid transit infrastructure on the property values in Colombia

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ABSTRACT

Several articles have theoretically and empirically verified favorable changes in the value (per square meter) of properties near urban mass transit infrastructure. The main purpose of this study was to demonstrate this effect under an unbiased specification using Geographical Information Systems (GIS) and advanced econometric techniques (Pooled Cross Sections, Spatial Econometrics, Box-Cox Transformation and Structural Change). Particularly, if the construction of the bus rapid transit (BRT) infrastructure impacted the price market (per square meter or asking price) of the residential and commercial properties in Bogota and Barranquilla (Colombia) with access to the BRT. Results indicated the true private monetary or higher valuation of such properties, caused by public investment over several years (1999–2011). This effect is conceived as a positive economic externality of the BRT projects.

1. Introduction

The main anticipated impacts of the bus rapid transit (BRT) systems, in the cities (of the developing countries) with more than 600,000 citizens, are: improved mobility through reduction of travel time, increased quality of life, and improved transport model operations to adjust for its ineffectiveness (World Bank, 2004). Also, the BRT systems are a major determinant for organizing economic activity in cities' geography (Redding and Turner, 2014).

The government, by means of public investment over the last 18 years (1999–2016) financed BRT projects in several Colombian cities (Bogotá, Cali, Pereira, Cartagena, Barranquilla, Bucaramanga and Medellin). This building strategy has become popular in other worldwide locations including Mexico, Hong Kong, Seoul, Curitiba, Chicago, Quito, India and Turkey (World Bank, 2004; Hidalgo and Gutierrez, 2013; Hidalgo and Huizenga, 2013).

Various economic and social studies have estimated the monetary values of the positive and negative externalities derived from BRT projects. They have also conducted numerous ex-post evaluations through cost-benefits analyses (CBA) to demonstrate the substantial social benefits of public investment in infrastructure (National Department of Planning, NDP, 2012). Likewise, their results have helped to draw fiscal instruments to continue financing new BRT projects in Colombia (World Bank, 2004).

As a result, several research projects have theoretically and empirically verified the economic benefits (land-use strategy, improving accessibility and reduction in air pollution) of constructing or expanding transport innovation infrastructure (Urban rail and BRT systems or Integrated Mass Transit Systems –IMTS–). Bocarejo et al. (2012), Geetam and Deepty (2012), Perdomo and Arzuza (2015), Moreno (2004), Perdomo et al. (2010), Sandoval and Hidalgo (2004), Lleras (2003), Herbert et al. (2002), Vinha (2005) and Bajic (1983) have analyzed the positive impact of BRT and urban rail systems on road safety, reductions in traffic accidents and crime rates, saving travel time, economic growth and the positives changes on land-value and higher valorization,

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respectively, using indicators, statistics and econometrics approaches.

Specifically, these studies confirm the favorable changes regarding the value (per square meter) of the properties near to urban mass transit infrastructure, using methods such as: Hedonic Pricing Models (conventional and –HPM– spatial –SHP–), *Difference in Differences* (*DD*), Propensity Score Matching (*PSM*) and other quantitative approaches (e.g., Rodríguez and Vergel, 2013; Perdomo, 2011, 2010; Rodríguez and Mojica, 2008; Perdomo et al., 2007; Mendieta and Perdomo, 2007; Ardila, 2004; Rodríguez and Targa, 2004; McMillen and McDonald, 2000, 2002).

Nevertheless, there are possible biases in the results due to inconsistencies in research methods (Ordinary Least Square –OLS–) or as a consequence of model specification errors, it is caused by omitted relevant variables (Suparman et al., 2014; Pace and LeSage, 2009), incorrect functional form, errors of measurement and incorrect specification of the stochastic error term or spatial autocorrelation –endogeneity– (see Greene, 2002, for a review). These inconsistencies, possibly, directly affect the accuracy of results when determining the impact of the BRT infrastructure on residential and commercial property values (based on Rosales et al., 2013, Ch. 1 and 2; Hill, 2013).

Owing to these factors, this study means to demonstrate this impact but (unlike many past studies) under an unbiased specification through the interaction of Geographical Information Systems (GIS) and advanced econometric techniques (Pooled Cross Sections, Spatial Econometrics, Box-Cox Transformation and Structural Change over time –2006, 2008 and 2011–). In this manner, Box-Cox is a technique that transforms a set of functions to stabilize variance and its regression produces the most accurate estimates of marginal attribute price (Cropper et al., 1998).

Structural Change Analysis, was used, because in Bogotá phase I of the BRT infrastructure (Transmilenio) was completed in 2000 and its expansion began in 2002 (phase II and phase III –partially– were finalized in 2008 at Bogotá) while for Barranquilla its phase I (Transmetro) was finished in 2010 (World Bank, 2004).

The main avenue for this analysis will be through determining the impact of the construction of the bus rapid transit (BRT) infrastructure on the market price (per square meter or asking price – willing to accept, WTA–) of nearby residential and commercial properties in Bogota and Barranquilla (Colombia). This paper organizes itself around several sections: Section 2 covers a literature review while Section 3 defines the interaction of analytical methodology (Pooling Cross Sections across Time, Hedonic Pricing Models, Box-Cox Transformation, Spatial Econometrics and Structural Change). Section 4 holds research microdata and empirical evidence, with a final conclusion taking place in Section 5.

2. Literature review

Previous studies conducted by many scholars of various disciplines (economics, geography, urban planning and design, business, finance and statistics) have shown favorable changes of values of the properties near urban mass transit infrastructure (e.g., Rodríguez and Vergel, 2013; Perdomo, 2011, 2010; Rodríguez and Mojica, 2008; Perdomo et al., 2007; Rodríguez and Targa, 2004; McMillen and McDonald, 2000, 2002), being profitable to their landowners. This has led to lively academic discussion, within which it is worth highlighting several aspects.

Krause and Bitter (2012) reviewed the association between spatial econometrics, land values, and sustainability, listing a series of articles. They focused their study on the expansion of spatial econometrics, the recognition of the differences between land values and improvement values, and acknowledgment of value premiums stemming from more sustainable forms of development.

Krause and Bitter extensively reviewed literature on spatial methods in valuation (spatial dependence and spatial heterogeneity), emergence of land values as a research interest (land values indices, real estate value decomposition, price volatility, and values leverage) and sustainability and property values (green building premiums and the value of compact development). They concluded that implementing and interpreting these topics is complex.

In spite of this, the empirical review to estimate changes in property values located close to IMTS infrastructure in a city, using quantitative techniques (HPM, SHP, PSM, *DD*, OLS, GIS and statistical comparisons –only with cross sections database–), is extensive (see Geng et al., 2015; Seya et al., 2013; Yokoi and Asao, 2012; Liu and Zheng, 2012; Perdomo 2011, 2010; Mendieta and Perdomo, 2007; Perdomo et al., 2007, Rodríguez and Mojica, 2008; Rodríguez and Targa, 2004; McMillen and McDonald, 2002).

In addition, Kiel and McClain (1995) and Gibbons and Machin (2005) were the pioneers using HPM, pooling cross sections across time and *DD* to calculate declines (or favorable changes) in residential property values near an incinerator or located close to the IMTS system, respectively. Particularly, Gibbons and Machin, textually argued that this "*...less common approach uses cross section time series data to implement a quasiexperimental or difference-in-difference methodology to look at before-and after outcomes in areas affected and unaffected by a transport infrastructure change*" (Gibbons and Machin, 2005, 150).

Although, the article of Gibbons and Machin is the only previous study accommodating the interaction between pooling cross sections across time and *DD* to calculate the goal impact in this study, there are no previous researches in which simultaneously using GIS and advanced econometric methods to obtain the unbiased effects in this paper.

Therefore, and unlike the literature review in this paper, interaction among several quantitative methods (GIS and advanced econometric) were used to improve the estimation of the unbiased effects of the BRT infrastructure (Transmilenio and Transmetro) on the value of nearby residential and commercial properties in Bogota and Barranquilla. The following section therefore contains the conceptual framework of this paper's analytical methodology.

3. Interaction of the analytical methodology

In accordance with the main purpose of this study and microdata available on property values (price per square meter), their physical characteristics (total number of bedrooms, bathrooms, garage, living rooms, living-dining rooms, kitchens, age, numbers of floors and architectural finish), location in relation to private and public equipment (minimum distance between the observed property and the closest BRT station or its terminal, banks, university, supermarkets, police station and fire station) and presence of externalities (proximity to farmers' markets, flood-prone areas, air pollution and crime rates).

Furthermore is relevant to note that recent studies (Perdomo et al., 2016) about economic segregation have used hedonic price model to define implicit prices of the public goods amount (police, fire station, parks and so on). Also in developing country (even Colombia, Bogota and Barranquilla) is very important the police station and fire station, due to the lack the public investment, poor and insecurity, that is different to industrialized country, it is the reason that these control variables are not typically seen in hedonic price models. In addition, these variables are important because they are similar to the effect of the BRT Infrastructure on property price, when public investment has been to provide public goods (police, fire station, parks and so on).

So, this work implemented the interaction of the following methods: pooling cross sections across time (under structural change over time –2006, 2008 and 2011–), hedonic price model (based on Rosen, 1974), Box-Cox transformation and spatial econometrics (by implementation of GIS –using the XY coordinates of the properties–, based on Haab and McConnell, 2002) defined as

$$P^{\theta}_{it} = \delta_0 D_{City-06-08} + \delta_1 D_{2008} + \rho \mathbf{W} P^{\theta}_{it} - \beta_1 x^{\lambda}_{1,it} - \alpha_1 \mathbf{W} x^{\lambda}_{1,it} + \gamma_1 D_{City-06-08} x_{1,it} + \ldots + \beta_k x^{\lambda}_{k,it} + \ldots + \alpha_k \mathbf{W} x^{\lambda}_{k,it} + U_{it} \qquad (1)$$

where P_{it} is the dependent variable or the price per square meter (price/m^2, WTA) of a property (i indicates the indexes individual, i = *property* 1, *property* 2, *property n*; n is a random sample size $-n$ = 1125 and n = 305, residential or commercial, respectively, see Section 4–) observed in the time period (indices time, t = 2006, 2008 and 2011).

$\beta_1, \ldots, \beta_k$, $\alpha_1, \ldots, \alpha_k$, δ_0 and δ_1 are the parameters; $x_{1,it}, \ldots, x_{k,it}$ are control variables (explanatory variables) or the property's physical characteristics, its location (Euclidean minimum distances calculated with GIS coordinates; Chiang, 1984) and presence of externalities, observed in t. $x_{1,it}$ is the effect variable as the minimum distance between the observed property and the closest Transmilenio or Transmetro station or terminal (Figs. 1 and 2). So, $x_{1,it}$ is considered more relevant in Eq. (1) to this paper.

θ and λ are the transformation coefficients of the Box Cox form ($P^{\theta}_{it} = \frac{P^{\theta}_{it}-1}{\theta}$, $\mathbf{W}P^{\theta}_{it} = \frac{\mathbf{W}P^{\theta}_{it}-1}{\theta}$, $x^{\lambda}_{1,it} = \frac{x^{\lambda}_{1,it}-1}{\lambda}, \ldots, x^{\lambda}_{k,it} = \frac{x^{\lambda}_{k,it}-1}{\lambda}$, $\mathbf{W}x^{\lambda}_{k,it} = \frac{\mathbf{W}x^{\lambda}_{k,it}-1}{\lambda}$), the Theta ($\theta$) and Lambda ($\lambda$) values are between -5 and +5, $-5 \leqslant \theta \leqslant 5$ and $-5 \leqslant \lambda \leqslant 5$. Thus, according to their results, the functional forms can be estimated by OLS (linear to $\theta = \lambda = 1$; double logarithmic to $\theta = \lambda = 0$; semi-log to $\theta = 1 = 1$ and $\lambda = 0 = 0$; log-linear to $\theta = 0 = 0$ and $\lambda = 1$; double reciprocal to $\theta = -1$ and $\lambda = -1$) to avoid incorrect functional form as they were, possibly, estimated in the research of the literature review section (Hill, 2013).

This is because, generally, their functional forms have been double logarithmic, without and real test. However, the values of θ and λ can be unknown parameters, so the regression in Eq. (1) is nonlinear in variables and parameters or Box-Cox form; therefore θ and λ are estimated by means of maximum likelihood method (see details, about Box-Cox form, in Rosales et al., 2013, 171; Perdomo and Hueth, 2011; Mendieta and Perdomo, 2008, 184–191 Greene, 2002, 173 and 174, for a review).

W is an inverse distance spatial weight matrix based on a 500 m cut-off –Euclidean minimum distances– (LeSage and Pace, 2010). It is an *nxn* positive symmetric matrix and contains information on the neighborhood structure for each location of the Bogota and Barranquilla properties. ρ denotes the spatial autoregressive coefficient, $\mathbf{W}P^{\theta}_{it}$ represents the endogenous interactions effects among dependent variables. $\mathbf{W}x^{\lambda}_{k,it} = \frac{\mathbf{W}x^{\lambda}_{k,it}-1}{\lambda}$ signifies the exogenous interaction effects among the independent variables and U_{it} indicates

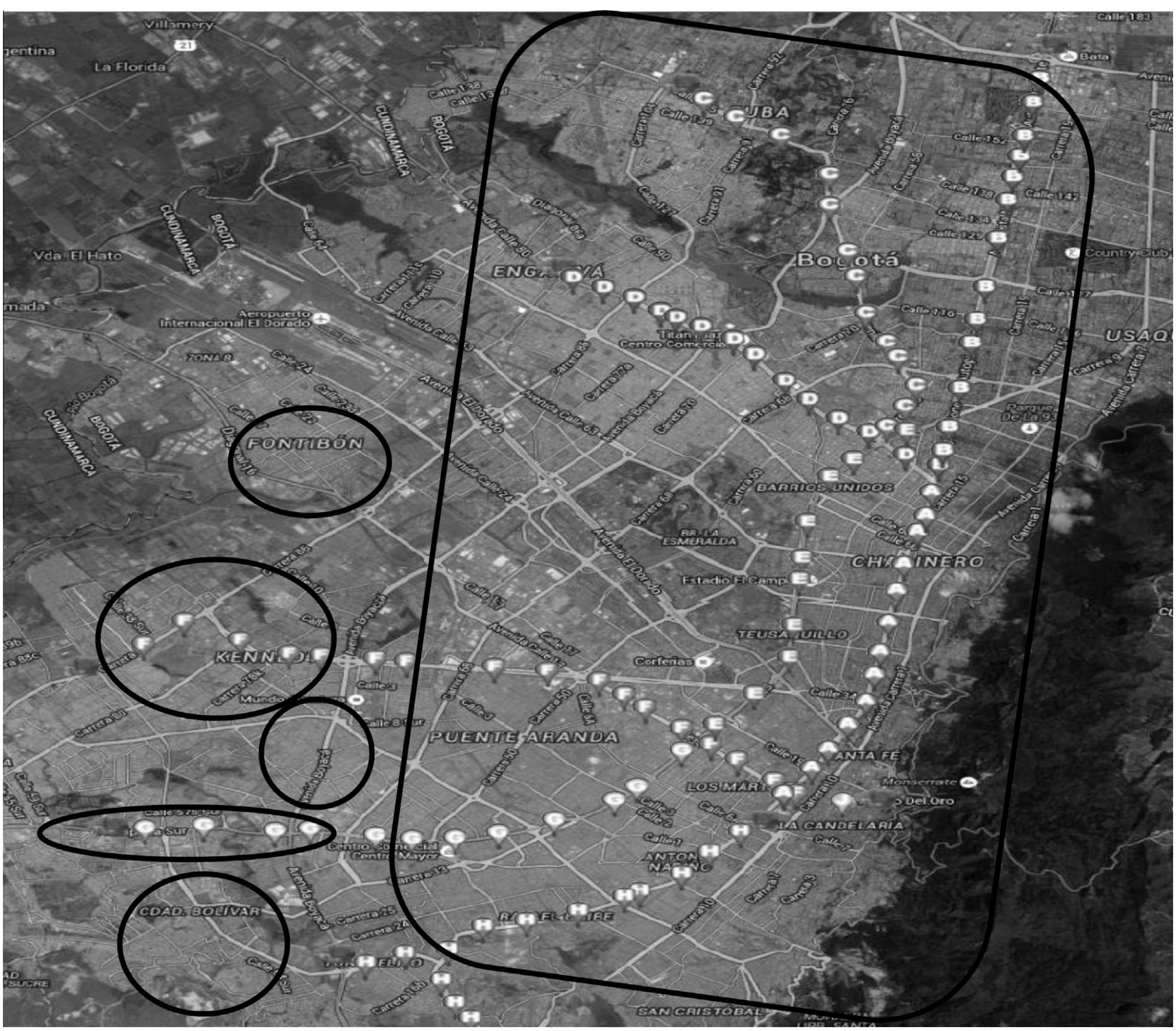

Fig. 1. The geographical extent of the simple random sample for Bogota zones (2006 and 2008). *Source*: http://www.colombiamania.com/transmilenio/.

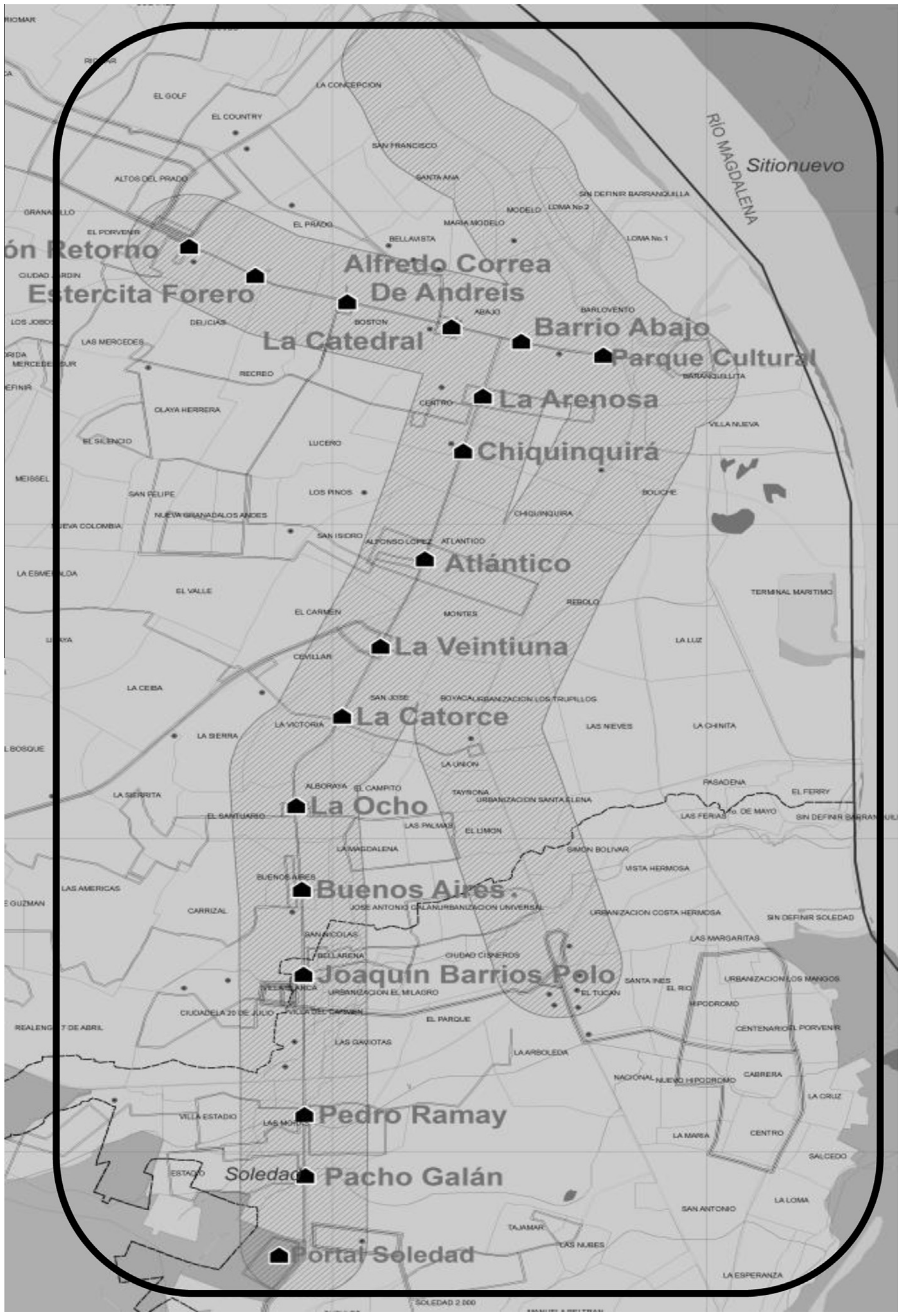

Fig. 2. The geographical extent of the simple random sample for Barranquilla zones (2012). *Source*: National Department of Planning (NDP, 2012).

the error term (identically and independently distributed, *iid*) with mean zero and unknown variance $-U_{it} \sim N(0, \sigma^2_{U_{it}})-$ (see details in Anselin, 1988; Anselin et al., 1996; Perdomo, 2011, 2010; Elhorst, 2010; Seya et al., 2013; Pace et al., 1998, for a review).

Dummy variables $D_{City-06-08}$ and D_{2008} consider the structural changes over time, capturing the differences in the dynamics of the property market in Bogota and Barranquilla during phases I and II of Transmilenio and phase I of Transmetro, respectively (World Bank, 2004; Hidalgo and Gutierrez, 2013; Hidalgo and Huizenga, 2013). Therefore, $D_{City-06-08}$ and D_{2008} distinguish differences in the intercept terms, the slope coefficients, or both.

Gamma (γ_1) and delta (δ_1) are the differentials slope[1] (β_1) values or the unbiased effect of the BRT (Transmilenio and Transmetro) infrastructure on properties in Bogota and Barranquilla (Colombia) in 2006, 2008 and 2011 (see details, about pooling cross sections across time –under structural change over time–, in Rosales et al., 2013, Ch. 7; Perdomo and Ramírez, 2011; Bernal and Peña, 2011; Cameron and Trivedi, 2009; Wooldridge, 2006, 2007, Ch. 13, for a review).

4. Research microdata and empirical evidence

Microdata used in the empirical evidence, by means of the interaction of the methods described above, was based on GIS (geographical coordinates). Moreover, three surveys during the years of 2006, 2008 (Bogota) and 2012 (Barranquilla) compiled the microdata. Figs. 1 and 2 exhibit circles that show the extent of the simple random samples at several zones for Bogota and Barranquilla.

[1] $\frac{\partial P}{\partial x_{1,it}} = \frac{-\beta_1 x_1^{\lambda-1} + \gamma_1 D_{Bogota-06-08}}{P^{\theta-1}}$, from the definition in Eq. (1).

Table 1
Descriptive statistics of the microdata set for residential properties.

Variable	Year	BRT-IMTS	City	Number of observations	Mean	Standard deviation	Minimum	Maximum
Price per square meter, WTA, – in constant (2011) prices, US Dollars	2006	Transmilenio	Bogota	206	600.38	147.76	144.53	1019.18
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2006	Transmilenio	Bogota	206	1070.80	568.87	43.53	1995.26
Total number of bedrooms	2006	Transmilenio	Bogota	206	3.04	1.22	1	15
Total number of bathrooms	2006	Transmilenio	Bogota	206	1.86	0.74	1	7
Total number of garages	2006	Transmilenio	Bogota	206	0.76	0.58	0	3
Total number of living-dining rooms	2006	Transmilenio	Bogota	206	1	0	1	1
Total number of living rooms	2006	Transmilenio	Bogota	206	1	0	1	1
Air Pollution-particulate matter (PM10)	2006	Transmilenio	Bogota	206	81.11	6.87	69	85
Age (constructed years)	2006	Transmilenio	Bogota	206	9.15	8.8	0	45
Land area (square meters, m^2)	2006	Transmilenio	Bogota	206	78.39	71.6	35	800
Price per square meter, WTA, – in constant (2011) prices, US Dollars	2008	Transmilenio	Bogota	488	584.53	593.27	41.63	4735.70
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2008	Transmilenio	Bogota	488	1144.17	825.71	57.17	3753.16
Total number of bedrooms	2008	Transmilenio	Bogota	488	4.3	2.75	0	23
Total number of bathrooms	2008	Transmilenio	Bogota	488	2.21	1.64	0	25
Total number of garages	2008	Transmilenio	Bogota	488	0.37	0.5	0	2
Total number of living-dining rooms	2008	Transmilenio	Bogota	488	0.9	0.92	0	6
Total number of living rooms	2008	Transmilenio	Bogota	488	0.36	0.67	0	5
Air Pollution-particulate matter (PM10)	2008	Transmilenio	Bogota	488	77.21	6.79	75	98
Age (constructed years)	2008	Transmilenio	Bogota	488	22.09	12.04	1	114
Land area (square meters, m^2)	2008	Transmilenio	Bogota	488	114	84.33	13	743
Price per square meter, WTA, – in constant (2011) prices, US Dollars	2011	Transmetro	Barranquilla	431	222.26	93.28	52.73	478.96
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2011	Transmetro	Barranquilla	431	1274.30	900.13	100.44	3599.51
Total number of bedrooms	2011	Transmetro	Barranquilla	431	3.06	0.85	1	6
Total number of bathrooms	2011	Transmetro	Barranquilla	431	1.31	0.53	1	4
Total number of garages	2011	Transmetro	Barranquilla	431	0.11	0.31	0	1
Total number of living-dining rooms	2011	Transmetro	Barranquilla	431	0.81	0.43	0	3
Total number of living rooms	2011	Transmetro	Barranquilla	431	1.02	0.21	0	4
Air Pollution-particulate matter (PM10)	2011	Transmetro	Barranquilla	431	17.56	2.69	14.6	20
Age (constructed years)	2011	Transmetro	Barranquilla	431	35.45	12.51	10	90
Land area (square meters, m^2)	2011	Transmetro	Barranquilla	431	89.66	20.66	10	450
Total number of observations (n)	1125							

The two Figures also indicate the dimension of the BRT infrastructure, the estates of which are in the samples according to affected and unaffected areas (less or more than 500 m away, respectively; CONPES 3185, 2012, 9). So, in Figs. 1 and 2, the whites and blacks points, respectively, are the paths of the BRT infrastructure (trunks, stations and terminals). In this manner, 1125 landowners of the residential properties and 305 landowners of the commercial properties provided information (price market or asking price –willing to accept, WTA–, physical characteristics, location in relation to private and public equipment and presence of externalities).

This data set in Bogota was used by Perdomo et al. (2007) in the vicinity of the Transmilenio Portal in Suba and intersection of Boyaca Avenue and 1 de Mayo Avenue[2]. During 2008, zones were located in Usaquén, Chapinero, Santafé, San Cristóbal, Usme, Tunjuelito, Bosa, Kennedy, Fontibón, Engativá, Barrios Unidos, Teusaquillo, Mártires, Antonio Nariño, Puente Aranda, La Candelaria, Rafael Uribe, Ciudad Bolívar and Suba[3] (Fig. 1).

While data set in Barranquilla, during 2011, was compiled in the study areas of the zones adjacent to the Via 40 Avenue (area unaffected by Transmetro system), Murillo Avenue and Olaya Herrera Avenue (zones with access to Transmetro system). These trunks were opened in April 2010 (Fig. 2). Additionally, the data on air pollution and crime rates come from Environmental Entities (IDEAM) and National Policy, respectively, for Bogota and Barranquilla zones (average per zone) in Figs. 1 and 2, during 2006, 2008 and 2011. Tables 1 and 2 detail their descriptive statistics (mean, standard deviation, random sample size, minimum and maximum values).

Results in Tables 1 and 2 show a wide variation in the main variables due to dissimilar sizes of random samples over time (2006, 2008 and 2011). Variation also happens because of the differences in the dynamics of the property market between Bogota and Barranquilla. In the interaction model –Eq. (1)– dummy variables ($D_{City-06-08}$ and D_{2008}) therefore consider the structural changes (intercepts and slopes coefficients) to capture these differences of the property market.

The trends lines (Figs. 3 and 4) clearly indicate an inverse relationship (linear association) between price per-square meter (price/m^2, WTA, in constant –2011– price, Y-axis), the minimum distance of a property (residential or commercial), and the closest BRT station or terminal (X-axis) in Bogota and Barranquilla over three years (2006, 2008 and 2011).

Similarly, as shown in Table 3, the difference in mean price/m^2 (WTA) among treatment and control properties (less and more than 500 m of the BRT system, respectively) is statistically distinguishable. So, according to the data in Table 1, Figs. 3 and 4 and Table 3, preliminary results were not theoretically expected. In this way, the information represented by the main variables is reliable for estimating the interaction model in Eq. (1), whereby

[2] The Lincoln Institute of Land Policy (LILP) provided project funding and published its findings in 2007.

[3] Project funding by the IDU (Instititudo de Desarrollo Urbano, is the government entity responsible for public infrastructure development and maintenance in Bogota).

Table 2
Descriptive statistics of the microdata set for commercial properties.

Variable	Year	BRT-IMTS	City	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Price per square meter – in constant (2011) prices, US Dollars	2006	Transmilenio	Bogota	33	1362.78	1443.90	52.66	7037.00
Minimum distance between the observed property and the closest IMTS station or its terminal	2006	Transmilenio	Bogota	33	304.45	188.31	323.95	615.32
Total number of bathrooms	2006	Transmilenio	Bogota	33	1.84	2.08	0	9
Total number of garages	2006	Transmilenio	Bogota	33	18.51	2.9	13	20
Age (constructed years)	2006	Transmilenio	Bogota	33	15.24	13.27	0	42
Crime rates-total number of robberies	2006	Transmilenio	Bogota	33	269.3	17.02	237	278
Air Pollution-particulate matter (PM10)	2006	Transmilenio	Bogota	33	81.6	6.64	69	85
Price per square meter – in constant (2011) prices, US Dollars	2008	Transmilenio	Bogota	261	2158.39	3185.82	51.34	21,351.12
Minimum distance between the observed property and the closest IMTS station or its terminal	2008	Transmilenio	Bogota	261	285.84	272.07	0	2019.03
Total number of bathrooms	2008	Transmilenio	Bogota	261	2.43	6.69	0	81
Total number of garages	2008	Transmilenio	Bogota	261	8.87	8.16	0	27
Age (constructed years)	2008	Transmilenio	Bogota	261	16.06	5.94	1	57
Crime rates-total number of robberies	2008	Transmilenio	Bogota	261	114.26	90.46	1	282
Air Pollution-particulate matter (PM10)	2008	Transmilenio	Bogota	261	75.52	3.45	75	98
Price per square meter – in constant (2011) prices, US Dollars	2011	Transmetro	Barranquilla	11	261.75	166.08	53.26	615.18
Minimum distance between the observed property and the closest IMTS station or its terminal	2011	Transmetro	Barranquilla	11	937.10	513.63	247.33	1720.56
Total number of bathrooms	2011	Transmetro	Barranquilla	11	1.09	0.54	0	2
Total number of garages	2011	Transmetro	Barranquilla	11	1.81	2.18	0	6
Age (constructed years)	2011	Transmetro	Barranquilla	11	32.85	7.9	18	42
Crime rates-total number of robberies	2011	Transmetro	Barranquilla	11	154	303.12	0	1042
Air Pollution-particulate matter (PM10)	2011	Transmetro	Barranquilla	11	19.02	2.19	14.6	20
Number of observations (n)	305							

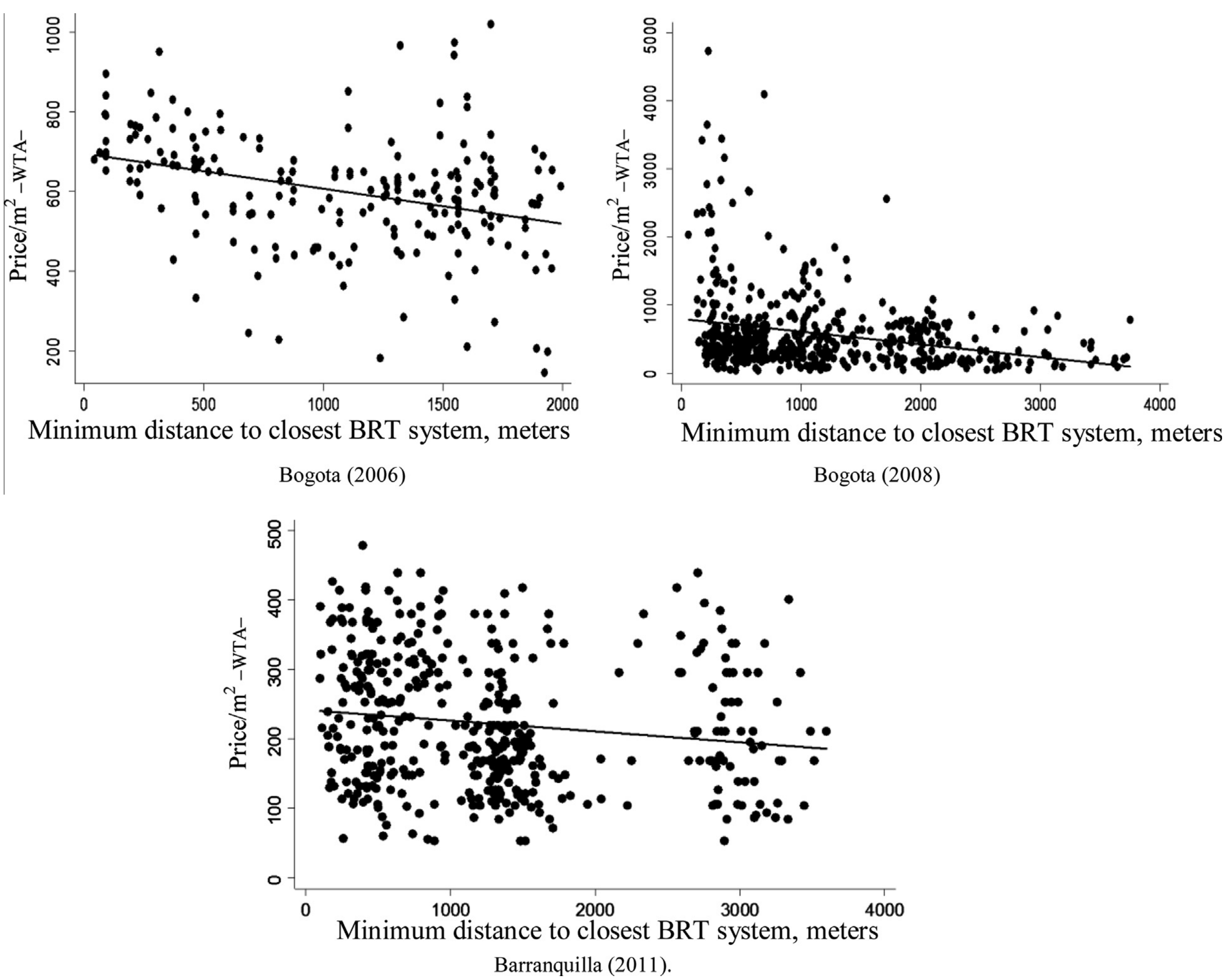

Fig. 3. Correlation analysis of residential property microdata set in Bogotá and Barranquilla.

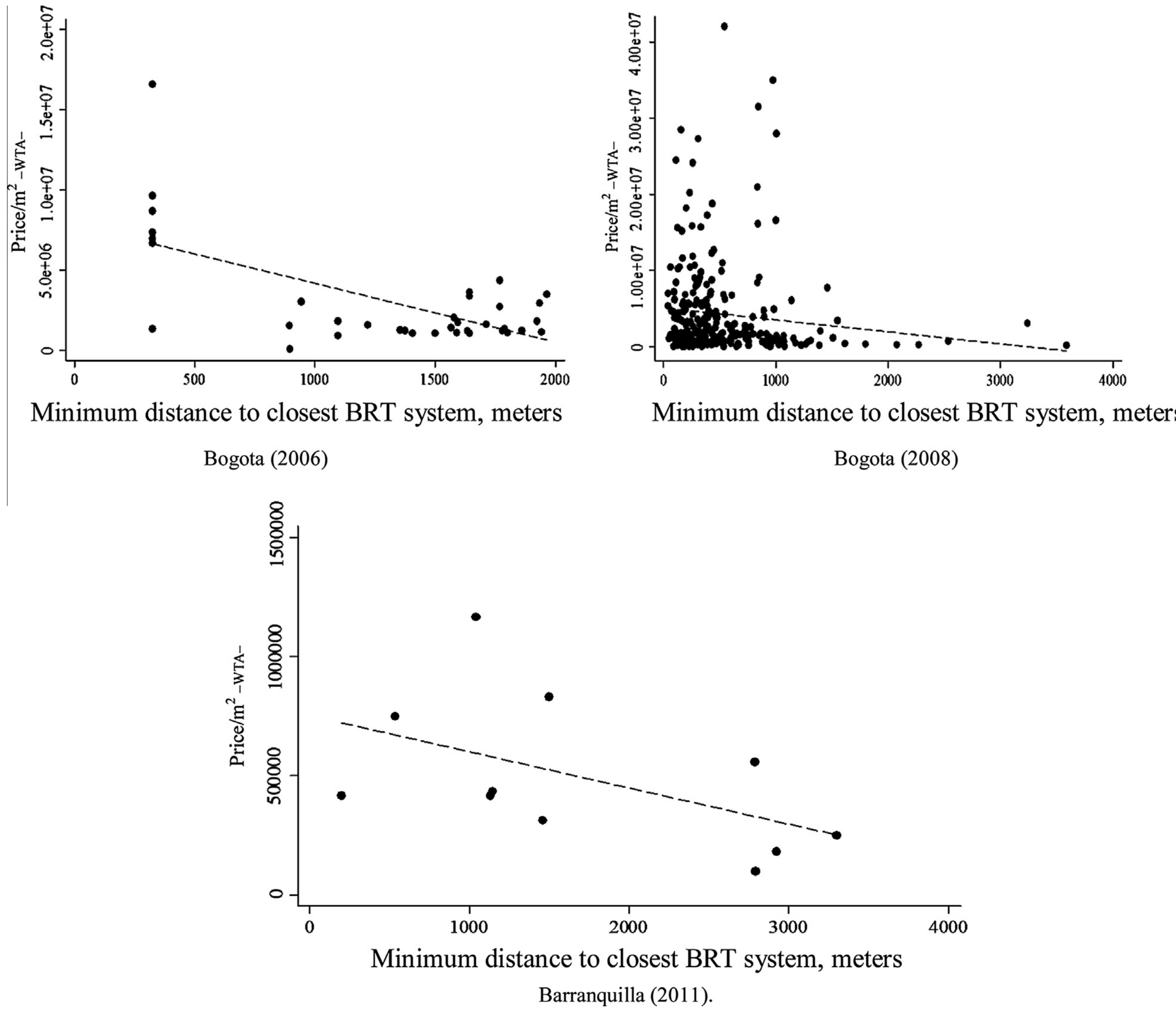

Fig. 4. Correlation analysis of commercial property microdata set in Bogotá and Barranquilla.

the estimations tend to improve the impact of the BRT system on the price/m^2 in Bogota and Barranquilla (Colombia).

Table 4 presents the regression estimates[4] of the interaction model in Eq. (1), the results of which use 25 explanatory variables pertaining to residential properties. This study used such variables as controls to describe the physical characteristics of each property, its location and presence of externalities to reduce biased estimators by the omitted variables problem (Hill, 2013; Rosales et al., 2013).

Although 11 explanatory variables were not statistically significant to explain price/m^2 behavior in Table 4, they maintained the expected sign with respect to the relationship between them. However, the estimator of the main exogenous variable (IMTSD) was statistically significant and presented the expected negative sign. This accurately demonstrates the impact of the BRT system on market price (price/m^2, WTA) of residential properties in Bogota and Barranquilla.

The inverse relationship between IMTSD and price/m^2 imply that the price/m^2 therefore decreases according to increasing distance from the BRT system. Specifically, if the IMTSD goes up by 1% (or by 1 m), on average, the price/m^2 of the housing goes down by about 0.10% (or by about US$0.04) in Bogota and Barranquilla. Indeed, the higher valuation per square meter associated with easy access to the BRT system in Bogota corresponds to approximately US$20.5 [(US$0.04 + US$0.001) * 501[5] = US$20.54; US$20.54 – US $0.041 = US$20.5)], while for Barranquilla it is approximately US $20 [US$0.04 * 501 = US$20.04; US$20.04 – US$0.04 = US$20)].

Thus, each household located in Bogota receives an average benefit of US$1965 [US$20.5 * 96[6]] whereas those in Barranquilla receive approximately US$1800 [US$20∗90[7]]. On the other hand, Table 5 presents the regression estimates[8] of the interaction model

[4] Geoda (spatial econometrics) obtained the spatial weight matrix (**W**), defined as the threshold distance (500 m, Euclidean Distance) between each residential property and its location in relation to private and public equipment. Stata 11 estimated the Box–Cox form in Eq. (1), using maximum likelihood method and robust SEs process to obtain efficient estimators.

[5] It is for a residential property to 501 m away of the BRT system, using a simulation between two housing (to less and more than 500 m of the BRT system, respectively).

[6] It is the average of the land area (m^2) in Table 1 for the residential properties in Bogota over years 2006 and 2008 ($\frac{78.39+114}{2}$).

[7] It is the average of the land area (m^2) in Table 1 for the residential properties in Barranquilla in 2011.

[8] Geoda (spatial econometrics) obtained the spatial weight matrix (**W**), defined as the threshold distance (500 m, Euclidean Distance) between each commercial property and its location to private and public equipment. Stata 11 was a means for estimating the Box–Cox form in Eq. (1), using the maximum likelihood method and robust SEs process to obtain efficient estimators.

Table 3
Two samples mean comparison tests to compare the average price per square meter.

Two group mean comparison test	Variable	Sample	Treatment Group Mean (properties have access to the IMTS)	Control Group Mean (properties without access to the IMTS)	Difference (price/m^2)
Residential properties microdata set in Bogota (2006), sample size is 206 observations, 156 for control group and 80 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars –WTA–	Non-Matched	US$694	US$570	US$124***
Residential properties microdata set in Bogota (2008), sample size is 488 observations, 364 for control group and 124 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars –WTA–	Non-Matched	US$838	US$498	US$340***
Residential properties microdata set in Barranquilla (2012), sample size is 431 observations, 329 for control group and 102 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars –WTA–	Non-Matched	US$250	US$214	US$36***
Commercial properties microdata set in Bogota (2006), sample size is 33 observations, 6 for control group and 27 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars –WTA–	Non-Matched	US$1560	US$471	US$1089**
Commercial properties microdata set in Bogota (2008), sample size is 261 observations, 43 for control group and 218 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars –WTA–	Non-Matched	US$2399	US$937	US$1462***
Commercial properties microdata set in Barranquilla (2011), sample size is 11 observations, 9 for control group and 2 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars –WTA–	Non-Matched	US$192	US$277	US - $85

Note: *, **, *** Significant at 0.10, 0.05 and 0.01 levels, respectively.

Table 4
Spatial hedonic price model (Box-Cox Transformation) of residential properties microdata set (2006, 2008 and 2011).

Explanatory variables	Dependent variable (price per square meter, constant –2011– prices, US Dollars, –WTA–) of residential properties at Bogota and Barranquilla		
	Coefficient	Marginal Effect (US$)	Elasticity
Intercept	7.56	–	–
W*(price per square meter –WTA–)	0.000001***	–	–
Minimum distance between the observed property and the closest IMTS station or its terminal (IMTSD)	−0.40***	−0.04	−0.10
Minimum distance between the observed property and the closest university (UNID)	−0.31***	–	–
Minimum distance between the observed property and the closest supermarket (SMARKD)	0.17***	–	–
Minimum distance between the observed property and the closest bank (BANKD)	−0.029		
W*(UNID)	0.000070*		
W*(BANKD)	−0.00042***		
Air Pollution-particulate matter (PM10)	−0.09		
Total number of bathrooms (nbatr)	0.01		
Total number of bedrooms (bebr)	0.18***		
Total number of living rooms (nliv)	0.07		
Total number of living-dining rooms (nlivd)	0.04		
Total number of garages (ngar)	0.06		
Age (constructed years)	−0.004**		
Total number of floors (nfloors)	−0.015		
Apartment (dummy variable, yes = 1 and no = 0)	0.24***	–	–
2008 (dummy variable, yes = 1 and no = 0, D_{2008})	0.86***	–	–
City over the years 2006 and 2008 (dummy variable, Bogota = 1 and Barranquilla = 0, $D_{City-06-08}$)	–	–	–
$D_{City-06-08}$*IMTSD	0.000092*	0.001	0.004
$D_{City-06-08}$*bebr	−0.25***	–	–
$D_{City-06-08}$*nfloors	0.11*	–	–
$D_{City-06-08}$*BANKD	−0.0002	–	–
Near to Farmers' Markets (dummy variable, yes = 1 and no = 0)	−0.12**		
Near to Flood Places (dummy variable, yes = 1 and no = 0)	−0.30**		
Architectural finish (dummy variable, yes = 1 and no = 0)	0.17**		
Lambda (λ)	−0.18	–	–
Theta (θ)	0.015	–	–
Number of observations (n)	1125		

Note: *, ** and *** Significant at 0.10, 0.05 and 0.01 levels, respectively.

in Eq. (1), which uses 21 explanatory and control variables to reduce biased estimators by the omitted variables problem. These results represent commercial properties.

Likewise, 11 explanatory variables were not statistically significant enough for explaining price/m^2 behavior in Table 5. Even so, they maintained the expected sign in the relationship between them. However, the estimator of the main exogenous variable (IMTSD) was statistically significant, presenting the expected negative sign. Particularly, this result accurately demonstrates the impact of the BRT system on the market price (price/m^2) of residential properties in Bogota and Barranquilla.

Thus, the inverse relationship between IMTSD and price/m^2 imply that the further away the commercial property is from the BRT system, the more its price/m^2 decreases. In other words, if

Table 5
Spatial hedonic price model (Box-Cox Transformation) of commercial properties microdata set (2006, 2008 and 2011).

Explanatory variables	Dependent variable (price per square meter, constant –2011– prices, US Dollars, –WTA–) of commercial properties at Bogota and Barranquilla		
	Coefficient	Marginal Effect (US$)	Elasticity
Intercept	11.57	–	–
W*(price per square meter –WTA–)	0.027**	–	–
Minimum distance between the observed property and the closest IMTS station or its terminal (IMTSD)	−0.160***	−0.39	−0.13
Minimum distance between the observed property and the closest university (UNID)	−0.082	–	–
Minimum distance between the observed property and the closest fire station (FIRED)	−0.150**	–	–
Minimum distance between the observed property and the closest bank (BANKD)	−0.052		
Minimum distance between the observed property and the closest police station (POLD)	0.004		
Air Pollution-particulate matter (PM10)	−0.86		
Total number of bathrooms (nbatr)	0.02		
Total number of garages (ngar)	0.03*		
Age (constructed years)	−0.03**		
2008 (dummy variable, yes = 1 and no = 0, D_{2008})	1.59	–	–
City over the years 2006 and 2008 (dummy variable, Bogota = 1 and Barranquilla = 0, $D_{City-06-08}$)	–	–	–
$D_{City-06-08}$*IMTSD	0.0005	–	–
$D_{City-06-08}$*BANKD	0.0013	–	–
Near to Farmers' Markets (dummy variable, yes = 1 and no = 0)	−0.80***		
Near to Flood Places (dummy variable, yes = 1 and no = 0)	−0.34**		
Architectural finish (dummy variable, yes = 1 and no = 0, af)	6.18***		
$D_{City-06-08}$*af	0.06		
$D_{City-06-08}$*PM10	−5.58*		
Near to mall (dummy variable, yes = 1 and no = 0)	0.93***		
Near to park (dummy variable, yes = 1 and no = 0)	0.30		
Near to Inter-Municipal Bus Station (dummy variable, yes = 1 and no = 0)	−1.99*		
Crime rates-total number of robberies	−0.0001		
Lambda (λ)	0.20	–	–
Theta (θ)	0.05	–	–
Number of observations (n)	305		

Note: *, ** and *** Significant at 0.10, 0.05 and 0.01 levels, respectively.

the IMTSD goes up by 1% (or by 1 m), the price/m^2 of the commercial property will lower by around 0.19% (or by about US$0.39).

The higher valuation per square meter associated with easy access to the BRT system in Bogota and Barranquilla corresponds to approximately US$195 [US$0.39 * 501[9] = US$195.39; US $195.39 − US$0.39 = US$195] per square meter. Thus, each commercial property benefits on average by about US$25,740 [US $195 * 132[10]]. Therefore, the BRT system has significantly impacted price/m^2 of residential and commercial properties in Colombia. Commercial properties have seen greater impact than residential areas as business owners tend to set up close to BRT stations or terminals.

5. Conclusion

Even though several articles have theoretically and empirically verified favorable changes in value (per square meter, WTA) of properties near urban mass transit infrastructure, the main purpose of this study was to also demonstrate this effect. However, this study distinguishes itself by using the interaction of advanced quantitative techniques (pooling cross sections across time, structural change over time –2006, 2008 and 2011–, hedonic price model, Box-Cox transformation and spatial econometrics –by implementation of GIS–) to unbiasedly estimate impact of the BRT system on market price (price/m^2, WTA) of residential and commercial properties in Bogota and Barranquilla.

Toward achieving this goal, was collected a random sample size of 1125 residential and 305 commercial properties. In this way was established microdata based on property values (price/m^2), their physical characteristics, location in relation to private and public equipment (minimum distance between the observed property and the closest BRT station or its terminal, banks, university, supermarkets, police station and fire station), and presence of externalities in Bogota and Barranquilla. Data pertained to the years 2006, 2008 and 2011.

The results of the regression estimates show the accuracy of favorable impact accorded by the BRT system on the market price (price/m^2) of residential properties in Bogota and Barranquilla in 2006, 2008 and 2011. Its marginal effect (−0.04) infers that each household located in Bogota receives an average benefit of US $1965 and US$1800 in Barranquilla. Similarly, each commercial property receives an average benefit of US$25,740. So, the BRT system has had an important impact on residential and commercial property prices/m^2.

Previous studies recognized favorable change of the market price (per square meter) of residential and commercial properties because of the BRT system; however, possibly, the studies overestimated the positive benefit of transit infrastructure on the market prices. There are possible biases in the existing results according to inconsistencies of the methods applied (OLS) or as a consequence of model specification errors.

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[9] It is for a commercial property to 501 m away from the BRT system, using a simulation between two properties (to less and more than 500 m of the BRT system, respectively).

[10] It is the average of the land area (m^2) in Table 1 for the commercial properties in Bogota and Barranquilla over years 2006, 2008 and 2011 $\left(\frac{156+138+102}{3}\right)$.

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