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Capitalization of BRT network expansions effects into prices of non-expansion areas

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ABSTRACT

A before and after hedonic model is used to determine the property value impacts on properties already served by the transit system caused by extensions to Bogotá's bus rapid transit system. Asking prices of residential properties belonging to an intervention area ($N = 1407$ before, 1570 after) or a control area ($N = 267$ before, 732 after) and offered for sale between 2001 and 2006 are used to determine capitalization of the enhanced regional access provided by the extension. Properties offered during the year the extension was inaugurated and in subsequent years have asking prices that are between 13% and 14% higher than prices for properties in the control area, after adjusting for structural, neighborhood and regional accessibility characteristics of each property. Furthermore, the appreciation is similar for properties within 500 m and properties between 500 m and 1 km of the BRT.

1. Introduction

Planners and policy-makers continue to show renewed interest in coordinating transportation investments and land development in order to provide alternatives to automobile commuting, and to decrease its negative effects. Terms such as "smart growth," "transit-oriented development" and "livable communities" embody the belief that the accessibility advantages provided by mass transit investments can be coordinated with compact land development. This development, in turn, is expected to support and reinforce the viability of public transit and other non-automobile transportation modes.

Simultaneously, the re-emergence of high service level bus systems is revolutionizing transit systems around the world. Bus rapid transit (BRT) is a bus-based mass transportation system that delivers comfortable, cost-effective mobility emulating rail transit (Wright and Hook, 2007). It relies on coordinated improvements in technology, infrastructure and equipment to deliver a high-quality level of treatment for buses (US General Accounting Office, 2001). Twelve Latin-American cities, three Australian cities, seven US cities, eight Asian cities and eighteen European cities have BRT systems in place. BRT systems actively under construction span the globe, including Dar es Salaam in Tanzania, Jinan in China, Bologna in Italy, Mérida in Venezuela, and Auckland in New Zealand. Wright and Hook (2007) cite estimates of GTZ that as of March 2007, there are at least 27 cities with active planning processes for building a BRT system.

The success of BRT is partly due to the cost-effectiveness and relative flexibility of the investments required. BRTs often can mobilize as many passengers as most conventional light rail systems at a fraction of the cost. BRTs also compare well with heavy rail systems, except when passenger demand exceeds 35,000 to 40,000 passengers per hour per direction on

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a line, a point at which levels of service deteriorate. As rail systems, however, the cost-effectiveness of BRT hinges on the ability to have supportive land uses that concentrate demand along system corridors. Therefore, in most cases BRTs have been built in corridors with proven demand. Yet, it is plausible that BRTs also attract dense development that will in turn benefit the BRT system in the future. This reciprocal connection between BRT investments and land development has been a cornerstone of Curitiba's development (Rabinovitch and Leitman, 1996). Despite the importance of this connection for the future viability and cost-effectiveness of BRTs, however, there is limited empirical evidence to support or dismiss the relationship between BRT investments and changes in development. Although this relationship is critical to the potential of BRT as a catalyst for urban growth and redevelopment, a recent World Bank (Halcrow Fox Inc., 2000) study observed, 'the impacts of busways on land use and city structure have been little researched'.

The present study addresses practical and conceptual gaps in the previous literature to investigate the relationship between the accessibility advantages provided by BRT system extensions, and its capitalization into residential home values using a generalized before and after evaluation. In a market economy, changes in land values are a first step in instigating investment decisions by land developers. The study aim is to quantify, for properties already served by BRT, the land value changes resulting from BRT network expansions occurring elsewhere in the city. In other words, the intent is to measure how the network expansions of BRT are capitalized onto land values of properties already served by BRT. To our knowledge, this effect has never been examined for BRT systems, yet in 2007 at least 14 existing BRT systems were considering expansions (Wright and Hook, 2007).

In the next section, we review the literature regarding the expected impacts of transportation investments, generally, and BRT in particular. The third and fourth sections discuss the hedonic analysis methodology employed and the data collected. Results of the empirical analysis and conclusions are provided in the last two sections of the paper.

2. Literature review

Land rent theory, advanced in an urban context by Alonso (1964) and Muth (1969) is commonly used to understand the relationship between the accessibility benefits of transportation investments and land values. Mass transit investments are expected to provide accessibility advantages to certain parcels over others. Because the number of parcels benefiting from enhanced access is finite, and assuming that access is a scarce good, households and firms valuing such benefits in a competitive market are expected to be willing to pay more for properties with good access over other properties, all else held equal. This applies equally to parcels where trips originate and where trips end (Martínez, 1995). As a result the access benefits provided by a transportation investment are expected to be capitalized into property values. As shown by Martínez and Araya (2000), the degree to which this occurs will depend on the sensitivity of users to the access improvements.

In the past 5 years alone, several studies have related land values to mass transit investments (Table 1). Access premiums consistent with theory have been identified for Seoul, London, San Diego and the Massachusetts suburbs. However, other studies have failed to identify appreciable effects. A meta-analysis of studies published up to 2002 and that examined the impacts of rail investments on property values, also found mixed evidence (Debrezion et al., 2007). Local land market characteristics, omitted variables, and the specification of access to the transportation infrastructure may contribute to explaining differences in results across studies.

For BRT, much of the discussion around the topic of the land value impacts of BRT is based on theoretical expectations (Halcrow Fox Inc., 2000; Polzin and Baltes, 2002). The first study examined HOV-bus lanes in Washington, DC, California, Seattle, and Florida (Knight and Trygg, 1977) using previously published reports, interviews, aerial photos, and other secondary sources available to conclude that exclusive bus lanes incorporated into highways appear to have no land use impacts upon either residential or commercial development. Mullins et al. (1990) analyzed the BRT systems of Houston, Pittsburgh, San Francisco and Ottawa. Only in the latter case the system appeared to have some effect upon land development in areas surrounding stations. More recently, a hedonic analysis applied to LA's first year with BRT (Cervero and Duncan, 2002a) did not detect any evidence of benefits having accrued to nearby multi-family parcels, although the lack of exclusive right of way and the newness of the service partly explain these findings.

Considered by many as a premier example of BRT (Cain et al., 2006), Bogotá's BRT system has been built over the last decade. The BRT is based on a successful public–private partnership, with the government funding the infrastructure and overseeing long-term planning functions, and private contractors bidding for the operation of a handful of BRT lines on a cost-plus basis. The system comprises specialized infrastructure, including exclusive lanes for high service capacity and articulated buses with off-board fare collection system. Access improvements around BRT stations such as widened sidewalks, improved pedestrian crossings, and enhanced lightning were made to increase the appeal of the BRT potential riders.

The land value impacts of Bogotá's BRT have been the focus of at least four studies. The first study relied on asking prices for apartment rentals to estimate spatial hedonic price models of BRT station access and land values in 2003 (Rodriguez and Targa, 2004). Accounting for spatial autocorrelation, the authors detected a premium of 6.8–9.3% for every 5 min walking time closer to BRT station. In the second study, Munoz-Raskin used data on property values provided by a local housing agency to determine that properties in the immediate walking proximity (0–5-min walk) valued more the access to feeder lines compared to properties in a 5–10-min walk (Munoz-Raskin, 2006). His findings also show that high-value properties were valued higher if they were close to a feeder line, but in the case of trunk lines, the effect was the opposite.

Table 1
Selected studies of the relationships between transportation investment and land values, 2003-present.

Authors	Data source	Selected results
Heavy rail rapid transit		
Du and Mulley (2007)	Asking prices of properties within 500 m of Sunderland Metro, UK extension stations relative to properties at least 1000 m from stations 1 year after opening	No changes in property values detected (using ANOVA)
Armstrong and Rodriguez (2006)	One thousand eight hundred and sixty single-family residential properties from four municipalities with commuter rail service and three municipalities without commuter rail service in Eastern Massachusetts, USA	Premium of 9.6% and 10.1% for municipalities with commuter rail
Gibbons and Machin (2005)	Seven thousand four hundred and seventy-four housing transactions from the Nationwide building society in London, UK and a wider area of South East England between 1997 and 2001	House prices rose over the period by 9.3% points more in places affected by these transport infrastructure changes
Mcmillen and Macdonald (2004)	Seventeen thousand thirty-four single-family house transactions and 4056 repeat sales observations from the Illinois Department of Revenue, USA	Premium of 3% for every .25 miles closer to transit station
Kim and Zhang (2005)	Appraised values for 731 commercial properties in Seoul, Korea	A premium between $1.69 and $7.54 per sq. ft. was detected depending on the property location
Bae et al. (2003)	Budongsan Bank data of 241 properties over 4 years data in Seoul, Korea	Premium of 8.9% within 1000 m of station due to station opening
Light rail transit/trolley service		
Cervero and Duncan (2002b)	One thousand four hundred and ninety-five sales of properties in multi-family housing in San Diego, USA in 2000	Premium for multi-family units between 2% and 6%
BRT		
Munoz-Raskin (2006)	One lakh thirty thousand six hundred and ninety-two new properties registered by the Bogotá, Colombia Department of Housing control between 2001 and 2004 and within BRT or its feeder lines	Premium for properties less than five minutes walking from BRT's feeder lines
Perdomo et al. (2007)	Three hundred and four residential properties and 40 commercial properties with or without access to Bogotá, Colombia's BRT	No premium was detected in five out of six tests. When significant, a 22% premium for properties with BRT access was detected
Rodriguez and Targa (2004)	Four hundred and ninety-four multifamily residential properties in a 1.5-km area around two corridors of Bogotá, Colombia's BRT	Premium of 6.8–9.3% for every 5 min walking time closer to BRT station

Note. Results apply to area and properties studied only. Refer to each particular study for details.

The third study was completed in 2007, using assessed property values from cadastral data to examine the relationship between distance to the BRT and property values (Mendieta and Perdomo, 2007). Assuming walking speeds of 4.39 km/h (Knoblauch et al., 1996), results show that property prices increased between 0.12% and 0.38%, depending on the distance to the BRT, for every 5 min walking time closer to BRT station. The fourth and final study used propensity score matching to compare asking prices of residential and commercial properties in two zones, one with and one without BRT access (Perdomo et al., 2007). The results were mixed, with most comparisons yielding statistically insignificant results. In only one case a premium of 22% for residential properties with BRT access was detected at a 95% level of confidence.

Although the evidence of the relationship between BRT and property values provides a base to build on further research, its ability to inform policy remains limited. For example, all studies to date rely on cross-sectional data. As a result, it is impossible to isolate whether the BRT caused the land value change, or whether planners sited the station in locations that were already valued by residents. Furthermore, despite the interest of policy-makers in expanding established BRT systems and finding ways to finance them, no studies have examined whether the benefits of are capitalized onto values of properties that were already served by the BRT system.

The potential benefits accruing from an enhanced BRT network reaching other parts of a city fall under the definition of an economic "network effect" (Katz and Shapiro, 1994). The additional destinations available from the network expansion are direct positive externalities to individuals currently served by the BRT. Network additions are complementary to existing networks (Economides, 1996). Although such effects are pervasive in transportation networks (Garrison and Levinson, 2006) their capitalization onto land values has been poorly studied. Particularly for high-quality transit service, whether regional access improvements are capitalized onto values of properties benefiting from existing service will determine the viability and extent of using value capture techniques to recoup some of the windfall capitalization enjoyed by these property owners.

In summary, although BRT is being embraced as an innovative solution for urban transport and urban redevelopment, some questions about the usefulness of BRTs for influencing urban form remain. Although the research available suggests that the land development impacts of recent BRT investments may be important, the cross-sectional designs and omitted variables remain a concern. This study is animated by the lack of existing research regarding the nature and magnitude of land value changes due to public-sector investments in BRT, and the increasing relevance of BRTs as transportation mobility solutions for several cities around the world. As a result, we hypothesize that the value of properties already served by BRT capitalizes the changes resulting from BRT network expansions occurring elsewhere in the city, all else held equal.

3. Methods

We apply a before and after approach with hedonic price functions (Rosen, 1974) to test the hypotheses. In a hedonic model, properties are characterized as a set of complex heterogeneous goods. Each property consists of an inseparable bundle of homogeneous goods or attributes that differ in values and characteristics. The underlying theory for the market of heterogeneous goods states that the value of the good is a function of the levels or value of each attribute in the bundle.

Hedonic models allow us to estimate prices of attributes that are not explicitly exchanged in observable market transactions. In the housing market, these attributes are usually structural and site characteristics of a property. Characteristics of the neighborhood area, quality of local services, and locational attributes such as accessibility to transportation systems or centers of activity are also part of the bundle of attributes. Similarly, hedonic functions can include temporal variables that measure variations in market conditions that influence value, including changes due transportation investments and accessibility.

To test our hypothesis, we use properties that before had access to a BRT station but that now benefit from the expanded reach due to extensions in the network. Following McDonald and Osuji (1995) the empirical relationship to be evaluated is the value of residential properties as a function of property attributes, of the general form:

$$V_i = c + \sum_j \beta_j \cdot X_{ij} + \varepsilon_i \tag{1}$$

where V_i is the nominal value of the ith property, X_{ij} is the jth attribute for the ith property, β_j is the estimated implicit empirical marginal price for the jth attribute, c is the intercept constant term, and ε_i is the random error term. Eq. (1) can be generalized to account for the year when properties were offered in the market. If data are available for time periods before and after the mass transit investments were made, then changes in values associated with the BRT intervention could be detected by the coefficient of the year variables.

In estimation, the data can be pooled to provide added flexibility for comparing parameters across years and gain efficiency. Assuming for parsimony that the coefficients β_j of each attribute X_{ij} remain unchanged across time, the resulting pooled equation can be written as:

$$V_i = c + \sum_j \beta_j \cdot X_{ij} + \alpha_2 \cdot year_{i2} + \alpha_3 \cdot year_{i3} + \alpha_4 \cdot year_{i4} \ldots + \alpha_t \cdots year_{it} + \varepsilon_i \tag{2}$$

where $year_{it}$ are dummy variables such that they take the value of one for observations offered in the tth year and zero otherwise, and α_t is the estimated coefficient for each dummy variable. The dummy variable for $year_{i1}$ (the first year) is excluded from the equation for identification purposes. The coefficients α_t determine the yearly appreciation of land values, after controlling for all other observables. In terms of our hypotheses, a larger increase in property values is expected for years after the BRT investment.

One limitation of Eq. (2) is that the effect of inflation and other secular changes in the property market cannot be isolated from the appreciation caused by the BRT investments. In other words, it may be that prices increased because the overall land market in the city was improving, not because of the BRT investment. As a result, in addition to having property data for time periods before and after for the areas affected by the BRT investment, we also include in our analysis properties from an area not directly contaminated or affected by the BRT investments. We label the former the intervention area and the latter the control area.

The derivation of the pooled hedonic equation that includes control and intervention areas follows the same logic as the derivation of Eq. (2), except that for parsimony we assume further that the implicit prices for each attribute X_{ij} are similar in both the control area and the intervention area. The resulting equation can be written as:

$$\begin{aligned} V_i = c &+ \sum_j \beta_j \cdot X_{ij} + \alpha_2 \cdot year_{i2} + \alpha_3 \cdot year_{i3} + \alpha_4 \cdot year_{i4} \cdots + \alpha_t \cdot year_{it} + \lambda_2 \cdot year_{i2} \cdot I + \lambda_3 \cdot year_{i3} \cdot I \\ &+ \lambda_4 \cdot year_{i4} \cdot I \cdots + \lambda_t \cdot year_{it} \cdot I + \varepsilon_i \end{aligned} \tag{3}$$

where I is a dummy variable such that it takes the value of zero for observations in the control area and the value one for observations in the intervention area. The coefficients for $\lambda_2 \ldots \lambda_t$ measure the estimated appreciation of property values by year for the intervention area after controlling for property value appreciation during the same year in the control area. Compared to each other, the coefficients $\lambda_2 \ldots \lambda_t$ determine changes in appreciation before and after the investment for the intervention area. The assumption that implicit prices for property attributes are the same across time and between intervention and control areas can be tested by interacting either the year dummy variables or the intervention dummy variable (or both) and the suspected property attribute(s), thereby introducing additional variables to the model.

Finally, estimation of Eq. (3) by means of OLS regression is optimal only when a number of assumptions are satisfied. Therefore, we account for two different forms of spatial autocorrelation that may violate OLS assumptions. One form is related with a lag term on the dependent variable. The other one occurs when the error term follows a spatial autoregressive process. Anselin (1993) defines the former as substantive spatial dependence, and the latter as spatial error dependence. The estimated coefficients will be biased under substantive spatial effects, while for spatial error dependence the coefficients will be inefficient but remain unbiased. Our approach is therefore to diagnose the presence and type of spatial autocorrelation by means of Lagrange multiplier tests (Anselin and Getis, 1992) and their robust counterparts (Anselin et al., 1996). Where spatial autocorrelation is detected, we use maximum likelihood methods to estimate a spatial hedonic price function, one that incorporates the same functional form as the OLS model, while simultaneously accounting for the specific type of spatial autocorrelation detected.

4. Study area

Data comes from a convenience sample of properties in the Bogotá metropolitan area between 2001 and 2006. Bogotá's BRT was inaugurated in December 2000, with significant extensions occurring on June 2001, December 2003, July 2005 and April 2006. Changes prior to December 2003 are collectively considered the first phase of the BRT system, while changes between December 2003 and April 2006 are considered the second phase. The December 2003 extension, along Avenida de las Americas, provides the setting for the study. Specifically, we use properties that were within 1 km of the BRT system before December 2003 and that benefited from the network expansion (Fig. 1). A 1 km buffer was chosen because that distance was used as the maximum walking distance in feasibility and economic evaluations of the BRT investment.

Property data come from a web portal in which real estate agents in Bogotá list properties for sale and rent (www.metrocuadrado.com). We focus exclusively on all residential properties listed in the database: single-family (attached and detached) and units in multi-family apartments. Data include information about the structure and the situation of each property. Structural characteristics of each property include the age, type of property, floor area, number of rooms, number of garages and number of bathrooms. By situation we mean the location of the property relative to surrounding places, local and regional. Consistent with urban economic theory and with the literature reviewed in Section 2, such data include the property's local and regional accessibility (distance to major employment centers, distance to major roads, and distance to transit routes that can substitute for BRT). Recognizing the importance of neighborhood-level externalities in influencing property values (Strange, 1992), we included also characteristics of local neighborhoods such as socio-economic status, density, and land uses.

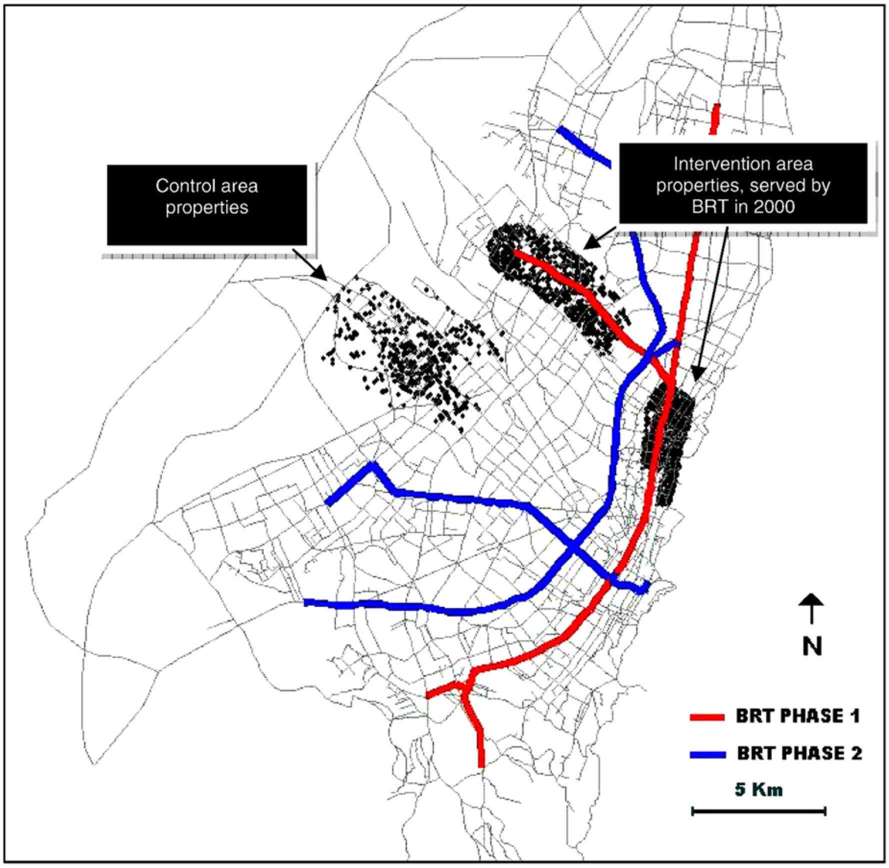

Fig. 1. Selected properties to study the network expansion effects of BRT extensions in Bogotá (2001–2006).

4.1. Dependent variable

The dependent variable is the natural logarithm of the nominal advertised selling price. In addition to other desirable properties (Malpezzi, 2002), the use of log transformed dependent variable is helpful in reducing heteroscedasticity as it compresses the scale in which the dependent variable is measured. One limitation of using the price at which the owner or manager is offering the property for sale is that the price is not directly linked to an equilibrium, where supply and demand for properties have cleared. Although we explored ways of gathering information on actual selling price or actual rental prices, privacy and security concerns prevented us from collecting it. As others, we assume that asking price is a surrogate for property values. Other studies have also relied on asking prices in hedonic price models (Benjamin and Sirmans, 1996; Cervero and Susantono, 1999; Cheshire and Sheppard, 1998; Du and Mulley, 2007; Henneberry, 1998; Rodriguez and Targa, 2004).

4.2. Independent variables

Because properties were offered between January 2001 and December of 2006, five dummy variables, one per year, were included in the model, with the year 2001 as the reference category. As presented in the methods section, the variables of interest are the year variables interacted with a dummy variable indicating whether the property belongs to the intervention area. Six interactions were included in the model, one per year beginning with year 2001 (*INTX2001, INTX2002, INTX2003, INTX2004, INTX2005* and *INTX2006*). The estimated coefficients for these variables measure the average asking price difference by year for the intervention area relative to the control area.

Many of the studies reviewed in Section 2 have shown that values vary by distance to mass transit stations. Therefore, the average effect estimated here for the intervention area is likely composed of higher values for some properties and lower values for other properties. To allow for further variation in the estimated effect by distance to the BRT station, we introduced six additional variables that identify whether a property is in the intervention area, the year it was offered, and whether the property is within 500 m of a station (*NRINTX2001, NRINTX2002, NRINTX2003, NRINTX2004, NRINTX2005* and *NRINTX2006*). These additional six dummy variables measure the extra price variation (higher or lower) of properties within 500 m of a station relative to properties beyond 500 m of a station, all located in the intervention area and for the same year.

We controlled for structural attributes of the property like its type (house or apartment), its age coded as a set of dummy variables (new – reference category, 0–10 years old, 10–20 years old, or more than 20-years old), number of rooms, number of bathrooms, number of garages (if any), the floor area (square meters) and, if an apartment, the floor in which the unit is located. The original data were notoriously incomplete for type of property and age attributes, so these values were imputed by best-subset regression, and dummy variables taking the value of one were created for each observation with imputed data and zero when the observation had full data. For a property's access to regional activity centers, we measure the road distance to Bogotá's Central Business District (CBD), defined as the downtown BRT station located in Calle 13. Although a second extended business district exists further north, a variable measuring access to this second center was highly collinear with the first measure, and thus we excluded it.

We also used information on demographic, social, land use, housing, homicides (per 100,000 residents), and transportation services of the neighborhood in which the property is located provided by Colombia's National Statistical Department (DANE) for 1999. The process of linking and calculating neighborhood variables relied on a definition of neighborhood as the 250 m circle around each property. Since the resulting buffer can cut through one or more neighborhood boundary, each neighborhood attribute was calculated as the average value of the boundaries intersected by the buffer, weighed by area of each neighborhood contained in the buffer.

Neighborhood variables include socio-economic stratum (SES), which is a direct measure of tax payments, utilities and related charges. SES was specified as a continuous variable, ranging from 1 (low) to 6 (high). We also control for population density, along with the land uses in the neighborhood measured as percentage of all area devoted to commercial, industrial, institutional, park/open space uses and vacant or abandoned lots.

Two final types of variables were included to account for the effect of proximity to roads on property values. The first (*PROX150M*) is a dummy variable that accounts for the potential nuisance effects of proximity to the BRT right of way such as pollution and noise. Jara-Díaz and Martínez (1999) modeled theoretically the importance of accounting for nuisance effects when examining transportation-land development interactions. The second type of variable was created to control for the relative access to non-BRT competing bus services operated on other major roads. For such properties, changes in accessibility brought by the BRT may not be as valued as in properties with limited access to other public transportation choices. Hence, six dummy variables (*CRA7, CLL72, AV_CCALI, AVBOYACA, AV68, CRA50* and *AV_LONG*) indicating whether a property is within 500 m of a major road served by competing public transportation were included in the model. Table 2 provides a summary of all structural, neighborhood and access variables used in the analysis and their sources.

5. Results

Table 3 summarizes selected characteristics of properties. Properties in the intervention area are more expensive than those of the control area before and after ($p < 0.00$). Asking prices increased at different rates across the two areas. Properties

Table 2
Structural, neighborhood and access variable descriptions and data sources.

Variable	Description	Source
PRICE	Asking price ($Col thousand pesos)[a]	www.metrocuadrado.com
Structural attributes		
APT	= 1 if property is an apartment	www.metrocuadrado.com or imputation
FLOOR	Floor number	www.metrocuadrado.com
AGE_1–10	= 1 if 1–10 years old	www.metrocuadrado.com or imputation
AGE_10–20	= 1 if 10–20 years old	www.metrocuadrado.com or imputation
AGE_20–30	= 1 if ⩾20 years old	www.metrocuadrado.com or imputation
BEDROOM	Number of bedrooms	www.metrocuadrado.com
BATH	Number of bathrooms	www.metrocuadrado.com
GARAGE	Number of garage spaces	www.metrocuadrado.com
AREA	Floor area (square meters)	www.metrocuadrado.com
Neighborhood attributes		
SES	Neighborhood socio-economic stratum 1–6 (1 = lowest)	www.metrocuadrado.com
POP_DENS	Population density (residents per sq km)	DANE
PCNT_INDU	% of neighborhood area in industrial uses, 1998	DANE
PCNT_COMM	% of neighborhood area in commercial uses, 1998	DANE
PCNT_INSTIT	% of neighborhood area in institutional uses, 1998	DANE
PCNT_VACANT	% of neighborhood area empty or vacant, 1998	DANE
PCNT_GREEN	% of neighborhood area of parks/open spaces, 1998	DANE
HOMICIDES	Homicides per 100 000 residents in neighborhood, 2001 and 2004	DAPD
Accessibility		
PROX_150 M	= 1 if within a 150 m of BRT right of way	GIS
CLL13	Distance between property and Calle 13 station (km)	GIS
CRA7	= 1 if within 500 m of Cra 7a	GIS
CLLE72	= 1 if within 500 m of Calle 72	GIS
CCALI	= 1 if within 500 m of Av Ciudad de Cali	GIS
AVBOYACA	= 1 if within 500 m of Av Boyaca	GIS
AV68	= 1 if within 500 m of Av 68	GIS
CRA50	= 1 if within 500 m of Cra 50	GIS
AVLONG	= 1 if within 500 m of Avenida Longitudinal	GIS

[a] $US 1 = $Col 1980 as of May 2007.

Table 3
Descriptive summaries of property characteristics by area and time period.

Variable	Intervention area				Control area			
	Before (n = 1407)		After (n = 1570)		Before (n = 267)		After (n = 732)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Price (thousands)	95222.23	72526.76	100053.90	77995.21	76517.63	77040.87	82387.20	73135.49
APT	0.55	0.50	0.70	0.46	0.76	0.43	0.84	0.36
FLOOR	1.87	2.37	2.66	2.87	2.31	1.95	2.65	1.89
AGE_1–10	0.16	0.36	0.14	0.35	0.26	0.44	0.22	0.41
AGE_10–20	0.61	0.49	0.59	0.49	0.66	0.48	0.64	0.48
AGE_20–30	0.23	0.42	0.25	0.43	0.04	0.21	0.07	0.25
BEDROOM	3.12	1.03	3.02	1.19	3.04	0.74	3.01	0.79
BATH	2.38	1.12	2.14	1.04	2.04	0.78	2.09	0.87
GARAGE	0.92	0.72	0.83	0.71	0.96	0.63	0.87	0.65
AREA	141.51	93.61	122.11	84.60	95.38	68.19	92.15	67.42
SES	3.57	0.73	3.54	0.73	3.37	0.91	3.41	0.81
POP_DENS	506.27	256.11	446.35	228.13	540.37	226.56	427.09	206.67
PCNT_INDU	0.48	2.91	0.87	3.85	22.76	28.63	16.39	22.28
PCNT_COMM	2.46	5.83	2.26	5.12	0.00	0.03	0.09	0.49
PCNT_INSTIT	5.86	8.51	8.24	10.17	1.47	1.96	1.71	2.23
PCNT_VACANT	0.82	3.30	1.63	5.11	14.08	13.02	14.12	11.28
PCNT_GREEN	2.02	2.41	1.97	2.37	3.96	8.22	8.78	15.88
HOMICIDES	72.81	37.93	77.71	38.82	155.89	85.14	116.00	79.33
PROX_150M	0.18	0.38	0.12	0.32	0.00	0.00	0.00	0.00
CLL13	8.38	3.41	8.56	3.67	9.95	1.61	10.19	1.37
CRA7	0.34	0.47	0.43	0.50	0.00	0.00	0.00	0.00
CLLE72	0.36	0.48	0.28	0.45	0.00	0.00	0.00	0.00
CCALI	0.07	0.25	0.06	0.25	0.12	0.33	0.23	0.42
AVBOYACA	0.08	0.27	0.08	0.28	0.42	0.49	0.16	0.37
AV68	0.06	0.24	0.04	0.19	0.01	0.12	0.02	0.13
CRA50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVLONG	0.10	0.30	0.11	0.32	0.15	0.36	0.31	0.46

in the control area appreciated an average of 7.7% between the before and after periods, whereas properties in the intervention area appreciated 5.1% for the same period. The hedonic models will determine the degree to which these changes in prices reflect overall price increases in the real estate market or the impact of new public amenities such as the BRT expansion, or other secular trends.

Price differences across areas may be the result of differences in the structural and neighborhood attributes of properties. Properties in both areas have similar number of rooms and bathrooms. However, the intervention area has larger properties than the control area. For neighborhood attributes all areas have similar neighborhood SES. The control area has significant amounts of industrial uses (22.7%) and vacant lots (14.1%), relative to the other areas (0.5% industrial and 0.8% vacant), even though population densities are similar. The control area has few commercial land uses, while the intervention area has a more balanced mix of residential and commercial land uses. In terms of homicides, the intervention area has a rate of 72.8 homicides per 100,000 residents, whereas the control area has twice higher rates.

Results from three different regression models are presented in Table 4. The first is an ordinary least squares model with robust standard errors and the second model is a weighted least squares (WLS) model. The OLS model showed significant spatial dependence in the form of both a spatial lag and spatial error, according the robust Lagrange Multiplier tests ($p < 0.00$). Hence, the third model controls for spatial dependence in the form of a spatial lag. The spatial weights matrix for the last two models was created using a row-standardized spatial weights matrix defined on observations within a 0.5 km distance of each individual property. The *W_LOGPRICE* variable in Table 4 is the spatial lag of the dependent variable. In all cases, the same set of independent variables was used. Since we had theoretical and empirical bases for the inclusion of all independent variables, they remained in the final models even if the estimated coefficients were far from being statistically significant.

Beginning with the variables measuring price changes per year (*YR_2002–YR_2006*) with respect to the baseline year 2001, we find little evidence of price changes until 2005. For 2005 the WLS model suggests an appreciation of 8.8%, and for 2006 the WLS and the spatial lag model show an appreciation of 12.1% and 10.4%, respectively. The price variations shown appear to be a good representation of Bogotá's market at the beginning of the decade, when the country was experiencing a strong economic recession. Fig. 2 shows the variation of Bogotá's real estate consumer price index as published by DANE. For comparison, price changes are shown in percentage terms relative to the first trimester of 2001. Consistent with our results, only by 2004 there is evidence of city-wide appreciation of real estate property.

To test whether the BRT expansion caused price changes due to its increased reach, we turn to the variables *INTXYR_2001* to *INTXYR_2006* and *NRINTX200* to *NRINTX2006*. The coefficients for the first group measure the asking price changes by year for the intervention zone relative to the control zone, all else held equal. Coefficients for the second group measure whether prices were similar for properties within 500 m of a station relative to properties beyond 500 m of a station. Table 4 shows a consistent higher appreciation from 2003 on for properties in the intervention area relative to the control area with the three models. Values for properties within 500 m of a station do not appear to be consistently different from values for properties beyond 500 m. The spatial lag and OLS model suggest values lower in 2002 and 2005 at standard levels of significance, but similar otherwise.

To communicate our findings more clearly, prices from OLS model coefficients for properties in the intervention (within and beyond 500 m of a station) and the control areas are depicted in Fig. 3. Fig. 3 was constructed with Clarify, a statistical program that uses stochastic simulation techniques to help interpret and present statistical results (King et al., 2000a,b). We drew 1000 simulations of the main parameters from an asymptotic multivariate normal distribution with mean equal to the estimated coefficients and variance equal to the coefficients' variance–covariance matrix. To calculate predicted prices for each simulation, we assumed that a property was between 10 and 20 years old and set all other variables to their median values, while changing the value of the temporal and intervention area dummy variables of interest to 1, depending on the year.

Fig. 3 shows that properties in the intervention area appreciated earlier and more than properties in the control area. However, standard errors of each estimate (not shown) are high partly due to the semi-log model specification, making prices in each area statistically indistinguishable from each other. Fig. 4 shows changes differences in prices between the intervention and the control areas in percentage terms. The 2003 spike in prices in the intervention may be the result of owner anticipation of the BRT extension opening or other real estate submarket changes not accounted for in our variables. Although similar anticipation effects for mass transit extensions have been documented elsewhere (Knaap et al., 2001), none have been examined or documented for the network expansion effects.

Although our interest was in examining the changes in property values over time for the intervention zone, other coefficients examined lend credence to our results. The coefficient of proximity to the right of way is negative but not statistically significant in any model. The effect of distance to the CBD is negative, but significant only for the OLS and WLS models. As expected, an increase of 1 km to the CBD is related to a decrease of 0.7–1.4%. The coefficients for the dummy variables measuring access to major roads (Carrera 7a, Calle 72, Avenida Boyaca and Avenida 68) shows the relevance of controlling for access to transportation options via different routes.

Neighborhood attributes such as socio-economic stratum, percent of open space/parks and percent of industrial uses have positive and significant coefficients. Neighborhood residential density was only significant for the spatial error model, having a negative sign. Finally, structural attributes are highly significant in the expected direction in all models. Variables such as the number of rooms, bathrooms and garages are positive at a 99% level of confidence. Similarly, the built area variable also correlates positively with the price of the property and its coefficient is highly significant.

Table 4
Hedonic price model of network expansion effects of BRT on properties in non-expansion areas, $N = 3976$.

Variable	OLS robust errors				Weighted least squares			ML spatial lag		
	VIF	Coefficient	Standard error	*t*-Statistics	Coefficient	Standard error	*t*-Statistics	Coefficient	Standard error	*t*-Statistics
YR_2002	11.29	−0.047	0.059	−0.79	0.034	0.045	0.76	−0.071	0.053	−1.38
YR_2003	12.02	−0.091	0.060	−1.56	−0.046	0.043	−1.06	−0.093*	0.050	−1.91
YR_2004	13.75	−0.034	0.054	−0.61	0.010	0.039	0.28	−0.033	0.045	−0.73
YR_2005	11.94	0.055	0.054	1.02	0.088**	0.038	2.21	0.051	0.044	1.15
YR_2006	9.31	0.095	0.058	1.59	0.121***	0.041	2.78	0.104**	0.048	2.09
INTXYR_2001	9.27	0.009	0.054	0.2	0.062	0.041	1.47	−0.046	0.048	−0.96
INTXYR_2002	7.54	0.103**	0.045	2.21	0.074*	0.040	1.78	0.073	0.047	1.52
INTXYR_2003	7.35	0.201***	0.044	4.2	0.172***	0.037	4.31	0.136***	0.043	2.98
INTXYR_2004	5.26	0.156***	0.030	4.82	0.167***	0.027	5.77	0.091***	0.032	2.78
INTXYR_2005	4.01	0.123***	0.033	3.55	0.156***	0.027	5.43	0.071**	0.031	2.22
INTXYR_2006	3.92	0.165***	0.040	3.87	0.234***	0.032	6.58	0.095**	0.038	2.44
NRINTXYR_2001	1.91	−0.040	0.032	−1.25	−0.048*	0.027	−1.8	−0.043	0.032	−1.39
NRINTXYR_2002	2.59	−0.065*	0.036	−1.84	−0.066**	0.030	−2.26	−0.069**	0.035	−2.04
NRINTXYR_2003	2.53	0.003	0.034	0.12	0.043	0.028	1.52	0.001	0.032	0.05
NRINTXYR_2004	1.95	−0.009	0.027	−0.33	0.010	0.023	0.42	−0.025	0.027	−0.93
NRINTXYR_2005	1.55	−0.052*	0.029	−1.78	−0.045	0.029	−1.59	−0.071**	0.033	−2.21
NRINTXYR_2006	1.45	−0.021	0.042	−0.48	−0.050	0.036	−1.41	−0.044	0.041	−1.08
APT	2.96	0.002	0.023	0.08	−0.021	0.017	−1.28	0.002	0.019	0.12
FLOOR	1.9	0.015***	0.002	6.6	0.016***	0.002	6.61	0.015***	0.003	5.15
AGE_1–10	6.27	−0.10**	0.041	−2.57	−0.107***	0.030	−3.74	−0.090***	0.035	−2.70
AGE_10–20	10.5	−0.046	0.042	−1.1	−0.067**	0.030	−2.31	−0.041	0.035	−1.20
AGE_20–30	7.56	−0.081*	0.044	−1.92	−0.109***	0.031	−3.68	−0.081**	0.036	−2.34
ROOM	2.6	0.079***	0.009	8.72	0.094***	0.007	13.61	0.082***	0.008	10.25
BATH	1.69	0.093***	0.007	12.48	0.093***	0.006	16.47	0.087***	0.007	13.22
GARAGE	1.27	0.147***	0.010	14.4	0.154***	0.007	21.35	0.141***	0.008	16.77
AREA	3.08	0.003***	0.00015	21.92	0.003***	0.00009	33.96	0.003***	0.00011	30.75
SES	1.43	0.197***	0.014	13.98	0.217***	0.007	30.73	0.184***	0.008	22.13
POP_DENS	1.57	0.000	0.00003	−1.33	0.000	0.00002	−0.71	0.000***	0.00003	−3.42
PCNT_INDU	1.93	0.003***	0.00056	5.08	0.003***	0.00043	6.37	0.002***	0.00050	4.23
PCNT_COM	1.25	−0.002	0.001	−1.32	−0.002*	0.001	−1.72	−0.006***	0.001	−4.93
PCNT_INSTIT	1.41	0.001	0.00086	0.97	0.001	0.00062	1.59	0.002***	0.00072	3.04
PCNT_VACANT	2.26	0.000	0.00102	0.39	0.000	0.00075	0.2	0.001	0.00087	0.79
PCNT_GREEN	1.79	0.005***	0.001	6.46	0.006***	0.001	8.16	0.002**	0.001	2.54
HOMICIDES	3.03	0.000	0.00017	−1.06	0.000**	0.00014	−2.37	0.000	0.00016	1.49
PROX_150	1.37	−0.014	0.021	−0.67	−0.007	0.017	−0.43	−0.020	0.020	−1.01
CLL_13	3.02	−0.010***	0.003	−3.23	−0.009***	0.002	−3.68	−0.001	0.003	−0.43
IMP_APT	1.53	0.080***	0.017	4.43	0.061***	0.013	4.45	0.071***	0.015	4.47
IMP_AGE	1.53	−0.069***	0.014	−5.12	−0.071***	0.011	−6.63	−0.069***	0.013	−5.50
CRA7	3.42	0.075***	0.024	2.98	0.065***	0.018	3.43	0.070***	0.021	3.22
CLL72	1.44	0.040**	0.016	2.53	0.028**	0.013	2.18	−0.011	0.016	−0.72
CCALI	1.33	−0.003	0.020	−0.16	−0.001	0.017	−0.08	0.007	0.020	0.35
AVBOYACA	2.01	0.045**	0.022	2.07	0.066***	0.020	3.28	0.021	0.023	0.92
AV68	1.15	0.045	0.030	1.49	0.067***	0.025	2.65	−0.027	0.029	−0.91
CONSTANT		9.601***	0.097	99.1	9.458***	0.064	147.49	5.372***	0.449	11.97
W_LOGPRICE		–	–	–	–	–	–	0.380***	0.040	9.59
R^2		0.694						0.701		
Lagrange Multiplier (lag)		155.45								
Lagrange Multiplier (error)		134.98								

*, ** and *** denote statistical significance at the 90%, 95% and 99% level of confidence (two-tailed tests), respectively. Other coefficients are not. Significant at standard levels of confidence.
Coefficients for dummy variables (in bold) are adjusted as suggested by Kennedy (1981).
The spatial weights matrix for the spatial lag and spatial error model is row-standardized and based on observations within a 0.5-km distance band.

6. Discussion

Our results suggest considerable appreciation of asking prices, likely due to the network benefits of mass transit extensions and the station area improvements associated with them. This is significant, given that prior studies had not examined or quantified the magnitude of these effects. The evidence is not conclusive, however, because such appreciation may be the result of local real estate submarket fluctuations related to earlier BRT investments made in 2000. For example, it is possible that the housing market in the intervention area appreciated more than the market in the control area for reasons related to the citywide recession of the early 2000s, although neighborhood-wide property price comparisons from other data sources does not suggest that this is strong possibility. Similarly, to the extent that our control area benefited from the BRT extensions, even indirectly, our calculations will be underestimating the true appreciation effect. This speaks to broader research

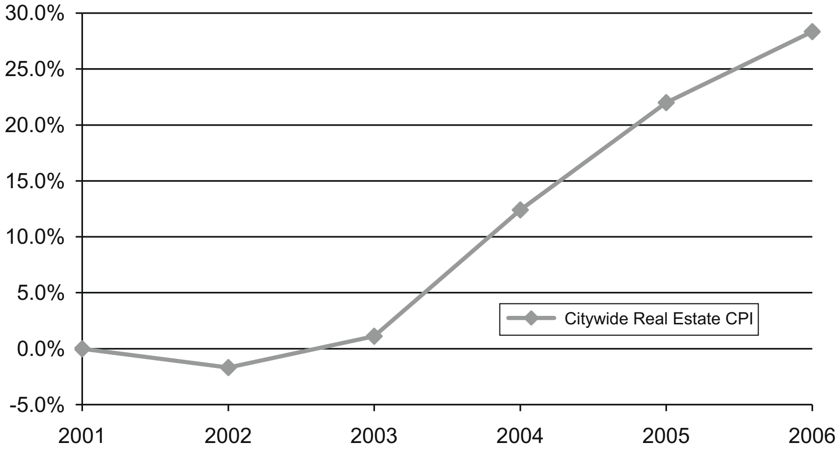

Fig. 2. Changes in citywide property prices (source: Departamento Administrativo Nacional de Estadística, DANE).

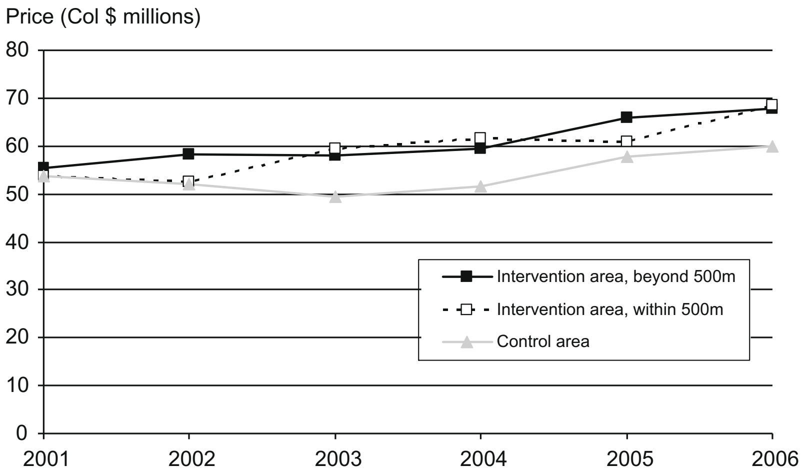

Fig. 3. Estimated yearly change in prices for properties in intervention and control areas based on estimated OLS coefficients.

design concerns including the potential bias that unobserved differences between the intervention and control zone can introduce.

Our results are limited because the capitalization of benefits of the extension may take time to occur. Our estimates of the price impacts cover only up to 3 years after the extension was inaugurated, but the development impacts of transit projects tend to take time to realize. Thus, it is possible that the appreciation detected stems from the benefits of the BRT investment (including station area improvements) in 2000, rather than when the extension was inaugurated. Furthermore, there are variations in local public services like police coverage and, in neighborhood environmental conditions like air quality that we did not measure. Second, our measures of land use are cross sectional. As such, it is possible that the anticipation of the BRT extension induced changes to development patterns that could affect property values. Third, it is possible that certain submarkets appreciate considerably more than others. To the degree that such heterogeneity is not captured by our research design, bias will be introduced into our results.

Other concerns included the high colinearity among many of the variables and the model heteroskedasticity. Variance inflation factors (VIF) are included in Table 4. A high VIF suggests high colinearity. The year dummy variables (*YR_2002–YR_2006*) have VIFs ranging between 10 and 14, which suggest that between 7% (1/14) and 10% (1/10) of their variance cannot be explained by other independent variables. Thus, it may be that the high colinearity is inflating the standard errors of the coefficients estimated. This is less of a concern for the product of the intervention and year dummy variables (*INTXYR_2001–INTXYR_2006*), having VIFs < 10.

Finally, the spatial model has significant heteroskedasticity, even after accounting for spatial dependence of the data. This suggests that standard errors can be underestimated. Visual inspection of residual plots suggested that the variables (*INTXYR_2001–INTXYR_2006*) were partly responsible for this. We included several polynomial terms for other variables

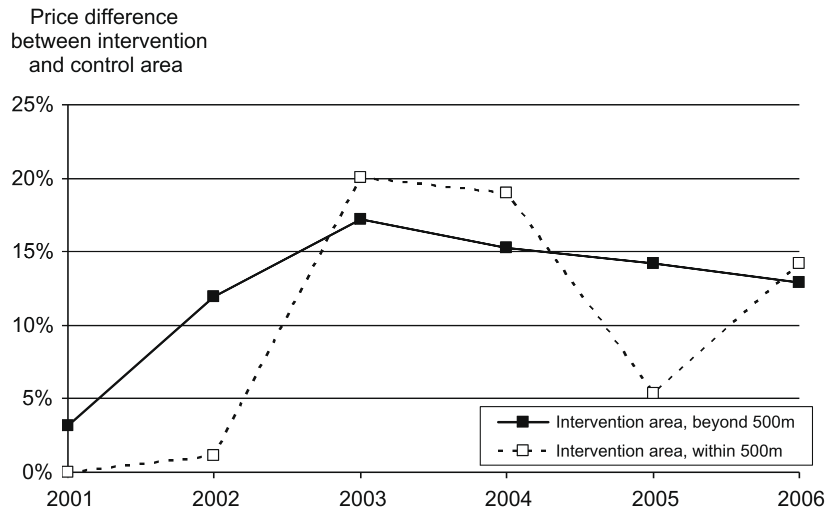

Fig. 4. Estimated yearly difference in prices (%) for properties in intervention and control areas.

associated with the dummy variables to remediate the problem but high heteroskedasticity remained. In the interest of model parsimony, those terms were removed from the final model.

7. Conclusions

This study is the first one to apply a before and after methodology with a control area to examine the property value changes resulting from the enhanced accessibility that residential properties already served by BRT when the system expanded to other parts of the city. Relative to a control area unaffected by the BRT extension, we identified asking price increases of 13–14% for the period after the BRT was extended. We also found evidence of anticipation effects for the year before the BRT was extended. However, the appreciation was similar for properties within 500 m and properties between 500 m and 1 km of the BRT.

The results support BRTs ability to attract dense development that will in turn enhance the BRT system in the future. The capitalization of accessibility benefits stimulates development by enhancing the attractiveness of parcels for development or redevelopment. Parcels that were not previously considered prime candidates for real estate investment appear more attractive after the transportation investment is announced or implemented. Alternatively, a parcel already developed or in the planning stages may be developed more intensely as a result of the increase in values.

In addition to the transit-oriented development potential instigated by the BRT network investments, land value increases are also relevant to municipal finances and project-specific financing. The success of local instruments such as tax increment financing and value capture hinges on the land value and related development changes associated with the project. By determining the capitalization of positive network expansion effects, the localized evidence from this study provides tools for exploring the usefulness of innovative land-based tax instruments that apply to areas benefiting from network extensions. Our results are expected to inform local transportation planners and policy-makers about the potential of public funding tools for transit infrastructure, such as value capture. Value capture represents an alternative approach of capital cost recovery that has not been fully explored and examined for funding mass transit investments. With BRT extensions and rail investments planned over the next decade for Bogotá, the network benefits quantified provide a basis for a broader and more nuanced conceptualization of the land value impacts of mass transit investments.

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