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Walking accessibility to bus rapid transit: Does it affect property values? The case of Bogotá, Colombia

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ABSTRACT

This research sheds light on the relation of bus rapid transit and residential property values within walking distance to the system. The case study was Bogotá's Transmilenio (Colombia). This research conducted a city-wide econometric hedonic analysis with 2000 to 2004 Department of Housing Control data across different walking distances, subsystems (trunk, feeder), socio-economic strata and time. The main results showed that, with respect to the value of properties in relation to proximity, the housing market places value premiums on the properties in the immediate walking proximity of feeder lines. The analysis by socio-economic strata showed that middle-income properties were valued more if they fell closer to the system, while there were opposite results for low-income housing. Finally, analysis across time reflects slight average annual increases in property values correlated with the implementation of the system in two specific areas analyzed. Throughout the paper, the author acknowledges some of the challenges of using hedonic modeling for property value impact assessments and emphasizes that the interpretation of the results are case specific.

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1. Introduction

1.1. Bogotá, capital of Colombia

Colombia is the second-most populous country in South America with 44 million inhabitants as of 2003 (UN, 2003) and can be considered a middle-income country. Bogotá is home to slightly more than 20% of Colombia's urban population, and it is the largest city in the country with an estimated population of 6.9 million in 2004 (US Department of State, 2005). It is a very compact city with an average population density of 230 persons per hectare (Suarez, 2005). Bogotá represents approximately 30% of Colombia's GNP and it is increasingly becoming a more service-sector-oriented city. As is common in Latin American cities, Bogotá has a notable income segregation. The city is classified into six different strata, named from 1 to 6, according to similar social and economic characteristics. This research paper aggregates them into low income (strata 1 and 2), middle income (strata 3 and 4) and high income (strata 5 and 6), with population share of, respectively, 43.7%, 50.0% and 5.3% (Hidalgo and Yepes, 2004).

The consequences of Colombia's social and political degradation were notable at the time that this research was conducted. In Bogotá, 49.6% of the population lived below the poverty line (2003) (El Tiempo, 2005). For many of the poor, it was extremely difficult to afford a home with even minimum standards, including land tenure or have appropriate access to basic services such as sanitation, education, health facilities or – as is the concern of this study – transportation.

1.2. Transportation improvements as a key component to improve the lives of the Bogotanos

Transportation is one of the services that shape the daily lives of Bogotanos. One of the principal forces determining city and residential location is the trade-off between transport costs and space (UN-Habitat, 2003). In this sense Bogotá's growth pattern has been a catalyst for social and economic segregation, and has divided the city into a northern section with planned residences for most of the middle and high-income dwellers, and a stigmatized southern section, which is associated with low-income and poverty. In addition, circumscribing the city, there is the third development pattern known as *cinturones de miseria* (misery rings), where most of the slums are now located.

For these reasons, it is very important to provide interventions to alleviate the mobility burden of the urban poor by reducing their commuting time and monetary costs. In fact, those living at the two lowest income levels spent an average 18% of their income on transportation (UNC, 2005). These figures are quite notable considering that these people had average daily incomes of US$ 5.6 (Hidalgo and Yepes, 2004). In the case of the middle

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income and high income people, their average daily income was, respectively, US$ 13.17 and US$ 48.44, and they also spent a significant amount of their income on transportation. The middle income population spent approximately 15%, and high income strata spent 12.7% (UNC, 2005). However, the opportunity costs are not as substantial, because their earnings allow them to meet their basic needs. Therefore, reducing transportation costs increases the available income and allows for a reallocation of funds to health, education or caring of children, among other possibilities (UN Millennium Project, 2005). For the poorest, the marginal utility of saving the monetary cost of a transportation ticket is significant. In order to save on the costs of transportation services, the poorest communities may end up landlocked in marginal peripheral areas, without adequate access to the areas where the job pools exist in the city.

This situation was identified by the City Government at the end of the 1990s. Since the immense majority of Bogotanos did not use private vehicles, transportation investments should be focused on public transportation and should not prioritize highway investments. In fact, patterns of urban mobility also reflected the social segregation existing in the city. At the time, in the absence of mass transit, public transportation service, serving mostly low and middle income population, was provided by obsolete, polluting and unsafe paratransit, with a modal share of approximately 70% (El Tiempo, 2005). As a consequence of the poor conditions of public transport, the City launched a long term mobility strategy based on non-motorized transportation, transit improvements and automobile restrictions. One of the major components of the plan was the creation of *"bus rapid transit" (BRT)* in order to provide mass transit.

1.3. The Transmilenio bus rapid transit system

Transmilenio is a BRT system that works with a trunk-feeder set-up. Based on the bus rapid concept that originated in Curitiba, Brazil, it operates with high-capacity articulated buses circulating in dedicated busways of one or two lanes in the trunk corridors. Operation in the trunk lines is done both with local and express services. Additional feeder lines (*alimentadores*) give free service to access the system from locations circumscribing the terminal stations of the trunk lines (portals). Unlike the main Transmilenio buses, feeders operate without dedicated lanes and are not articulated buses. The implementation of Transmilenio started in 2000. As of April 2007, its first two phases were implemented, achieving 84 km of dedicated busways and 541 km of feeder lines with a ridership of more than 1.5 million trips per day (Transmilenio 2007). Trunk corridors were implemented in city areas that were generally of low and middle income socio-economic strata, although they also crossed through areas that were predominantly high-income strata. Feeder lines were mostly located in peripheral low-income areas at the end of the trunk corridor's terminal stations.

In terms of ticketing, Transmilenio system has an integrated fare policy. In the case of the feeder line service, it functions with a free service that takes passengers to the portals where the user pays to enter the trunk system. On average, the ticket cost was higher than the cost to ride paratransit services. In June 2005, a Trasmilenio ticket cost 1200 Colombian Peso (US$ 0.51) and paratransit services were offered between 900 and 1200 Colombian Peso (US$ 0.39 and US$ 0.51 respectively).

1.4. Transmilenio's direct effects on transportation operation

One of the most notable effects of the implementation of Transmilenio was that it substantially decreased public transport travel times in the corridors where it was implemented. An increase in commercial speed was quantified from 12 km/h in Avenida Caracas and 16 km/h in Calle 80 corridors before the implementation of Transmilenio, to 26 km/h after implementation (Transmilenio, 2005). Also, comparing 2005 modal share figures with 1999, Transmilenio captured approximately 15% of the modal share from paratransit and 5% from automobile users (El Tiempo, 2005).

The ticket pricing of the system has a competitive price scheme compared to paratranisit when the user can access it on foot. It also brought notable cost savings for long distance transit users, mainly unskilled, low-income workers living in the periphery, who could not benefit from an integrated ticketing system with the previous paratransit services. However, those users who still depend on different forms of paratransit to reach the BRT and pay double for their commute, due to the transfer, do not benefit from current ticketing policy. Furthermore, low-income individuals may still use privately-run public transportation, since there is a high marginal utility of the savings between the Transmilenio prices and the paratransit private operator prices that can help the person save up to 300 Colombian Pesos (US$ 0.12) if advertised prices of both services are compared. The poorest may still be willing to take the slower paratransit in parallel corridors at lower prices in order to save money, trading-off longer commutes to get to their destinations under poor transit conditions.

According to Transmilenio S.A., 37% of BRT passengers belonged to low-income strata, 60% belonged to middle-income, and only 3% belonged to high-income strata (Transmilenio, 2005). From these figures, it can be observed that with the existing income levels and pricing policy, Transmilenio's average user was the middle-income strata citizen, and neither the poorest nor the wealthiest represented the same share of commuters as their percentage of population in Bogotá (see Fig. 1). However, it is remarkable that there was a notable increase in usage by people from the low-income population in the three first years of operation from 17% to 37% of trips (Hermann and Hidalgo, 2004).

1.5. Transmilenio as a catalyst for environmental and social improvements

Although Transmilenio brought notable operational transportation improvements to Bogotá, its influence was also related to public space. The implementation of the system also encompassed the renovation of the urban areas in the proximity of the system, with numerous indirect effects. The BRT system reduced accidents in its corridors by 74.3% (individual run-over by 62% and deaths by 83%) (Transmilenio, 2005). Transmilenio was also a catalyst of a decrease in crime rates, with a 86% reduction in crime rates in the walking proximity to Avenida Caracas trunk corridor after the implementation of Transmilenio. This reduction in crime rates was related to improvements in street order, street cleanness, public space renovation, greater policing, traffic improvements, etc. (Moreno, 2005).

2. Research questions

Since the direct and indirect effects of Transmilenio have improved the lives of many city dwellers, this may also be reflected in the real estate market. However, there are very few studies on the effects of BRT on property values, and, in particular, in the case of Bogotá. This study quantitatively analyzes the effects of Bogotá's Trasmilenio BRT system on residential property values within a 10 min walking proximity to trunk stations and

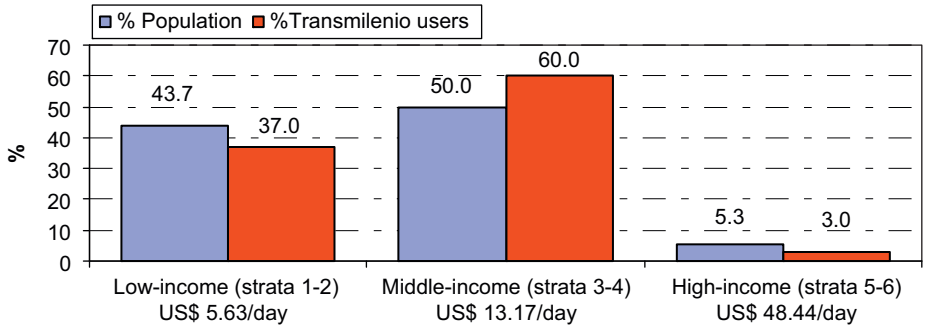

Fig. 1. Percentage of population of Bogotá and Transmilenio users by income level. Data source: elaborated with data from different institutions referred in Hidalgo and Yepes 2004.

feeder lines of the system. Specifically, the study will address: (i) whether there was a correlation between average property value and proximity within walking distance to the BRT system, (ii) whether there was a correlation between average property value and proximity within walking distance to the BRT system, limiting the analysis to low-income, middle-income and high-income strata housing markets, and (iii) how the implementation of BRT affects residential property values within a ten-minute walking distance to the system.

3. Literature review

Literature on the relation between proximity to transit and land and property values reveals that the implementation or existence of transit stations in the proximity of a specific commercial or residential property can be linked to indirect effects such as variations on property values. Proximity to transit is related to specific attributes of the property value, such as an increase in accessibility to the transit network and a potential reduction of the transportation costs of the household unit. However, other specific attributes of the transportation network, station design, or the socio-economic circumstances of the neighborhood can actually outweigh the positive indirect effects and result in a decrease of the value of the properties in the proximity of a transit station. These negative attributes could be noise, vibrations, pollution, visual impacts and safety issues, among others (Bowes and Ihlanfeldt, 2001).

The literature regarding the relationship between proximity to transport or accessibility improvements and land value is vast. Most of the research to date have focused on residential property, as opposed to commercial property values, mainly because the data are more easily accessible. At the time this research was conducted, the most comprehensive study identifying the relationship between land value and public transport was from The Royal Institution of Chartered Surveyors from the United Kingdom. This research located approximately 150 recent references on the relation between land and property values and public transportation and drew relevant conclusions from the literature reviewed. One of its most important findings is that almost uniformly, empirical evidence in studies in the United States and Europe reveal a positive correlation between proximity to public transport and property or land values. However, the percentage differences are derived from variations in either the importance of other independent factors (zoning, regulatory framework, macro-economic conditions, etc.), the specificity of the results or the limitations of the methods used (or a combination of these factors) (RICS, 2002). In addition, after reviewing hedonic modeling literature in the United States and in Europe, Martínez and Viegas discuss the enormous variability in impact points on land values associated to proximity to transit, and associate this with either the importance of omitted variables, the specificity of results, the limitations of the methods used—or a combination of all three factors (Martínez and Viegas, 2008).

Relevant research was also conducted by Huu Phe and Wakely. The authors argue that the traditional market approach focus on the city centre(s) and distance(s) from it (or them) ignores a number of social attributes, which are the essential trade-off between location and property values. Thus, they argue that the focus should be shifted to two other categories of parameter: housing status and dwelling quality—a quality-status model (Huu Phe and Wakely, 2000).

Some authors point out that if the transportation network is already consolidated and a new station does not bring substantial accessibility improvements and the marginal effect on land and property values is negligible (Rolon, 2005). Another interesting condition could be related to the motorization rate or the need for accessibility: if the transit station is located in an area where very few people use public transit but prefer automobiles, the effects on property values might be inappreciable. Hall and Marshall noted that transportation infrastructure investment has led to land use development in buoyant economic contexts, and that public transport-led development in particular, has tended to flourish where planning policy favored public transport-oriented development and/or restricted car use/car-oriented development (Hall and Marshall, 2000).

At the time this research was conducted, the amount of literature explicitly showing empirical evidence of the effects of BRT on property values was limited to three studies. Although none of them studied residential property values, but only land or rent values, their conclusions are relevant to this research since all these markets are correlated and the empirical findings can serve as proxies of the property value market behavior.

In 2002, Cervero and Duncan conducted an analysis of different kinds of residential and commercial properties in the proximity of the Los Angeles Metro Rapid BRT. This study concluded that residential properties in the proximity of BRT generally sold for less, whereas commercial properties generally sold for more (Cervero and Duncan, 2002). However, extrapolation of these results to other BRT should be approached with caution since the BRT had only been implemented one year before. Significant increases in ridership were already notable, and new studies in the future could reveal the sustained effect of the implementation of BRT on the property values. In addition, the Los Angeles BRT was implemented in a totally different setting and socio-economic context from that of this research study: it is a line implemented in an industrialized country, with lower housing densities and travel patterns that are substantially automobile based.

For this reason, the only studies conducted in similar circumstances are those by Barrios (2002) and by Rodriguez and Targa (2003). Both of their analyzes were conducted on the effects of Transmilenio on advertised residential rent values using similar data from the first half of 2002. They indicated that, holding all other independent variables constant, there is a 0.0421% increase in rent value for every additional 1% increase in the proximity to Transmilenio Avenida Caracas and Calle 80 trunk corridors (Barrios, 2002) and that for every 5 min of additional proximity on foot to the BRT station, the rental price of the property increased by between 6.8% and 9.3% (Rodriguez and Targa, 2003). However, their spatial analysis was framed in a specific time frame (2002) and did not have a time series to be able to isolate the premium on property values derived from the proximity to the trunk corridor's avenue that is related to the actual implementation of the BRT trunk corridor. Consequently, there has not been any historical analysis of the factual value premium imposed on property values in the proximity of Transmilenio to date. In addition, these studies focused on the trunk lines without evaluating the effects of the increased accessibility on the areas surrounding the feeder lines and controlling with the rest of the prices of housing elsewhere in the city.

4. Methodology

4.1. Hedonic model

The estimation of the effects of the accessibility to Transmilenio for this research is based on the use of multiple regression analysis through a hedonic model. This methodology differentiates the value of the products (residential property values) based on the assumption that they are valued for their utility-bearing attributes (Rosen, 1974). In other words, this means that the value of the product is a sum of the values that the consumer gives to each of the different attributes that constitute it. The usefulness of this kind of the hedonic price function is that it allows for the estimation of the prices of goods that are not explicitly exchanged in observable market transactions (Rodriguez and Targa, 2003).

The general model for the estimation of the value of a product, y, is typically represented in this manner:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + u$$

where:

y: value of dependent products (such as the property value),

β_0: intercept (constant),

β_1 to β_k: slope coefficients (implicit marginal effect of each attribute x_i on y) (constants),

x_1 to x_k: independent or explanatory variables (such as the size of the property, the date of the development, the proximity to the rail station, etc.),

u: value of the error term of the model.

Although hedonic modeling is the most commonly used methodology in research to determine the relation of accessibility of transportation to the real estate market, it assumes that homebuyers have the opportunity to select the house they are purchasing with costless transactions, and complete information about all the characteristics and of all the housing units in the universe under analysis. However, in reality, only a selection of the housing units are available in the market at a specific time, and the information that the homebuyer receives is limited. Therefore, the availability of housing for the buyer is never the whole sample (Dellecker, 2004). Thus, it should be taken into account that this modeling tool has some inherent weaknesses. This issue will be further developed in the "policy implications and further research" subchapter later on.

4.2. Data base

The data base used for this study was obtained from the Department of Housing Control (DHC) (*Subsecretaria de Control de Vivienda)*. The sample consists of 1495 new legal developments of five or more housing units for the whole city of Bogotá from 2000 to 2004. In this city, all housing developments of five or more residential units must request permission from the DHC. The data base had the following attributes relevant to this research for each development: asking price for residential housing units in legal developments of five or more units; number of units per development; size of the housing units in the development; socio-economic stratum of the area where the property is located; and year the development entered the market. These variables are the best available data to merge market and quality-status analytical approaches.

The total amount of valid observations registered by the DHC was 130 692 housing units. The data base did not include the 23% estimated informal development that existed in Bogotá at the time (SCV, 2003), the second hand market or the legal developments of four-or-less units. It is important to keep in mind that, as mentioned by Redfearn, common empirical approaches to measuring the value of proximity can be highly sensitive to choice of subsample and to the parametrization of the proximity itself (Redfearn, 2007). This fact is especially important in the interpretation of the research results, which would vary if the whole housing market could have been part of the data source. This intrinsic limitation for housing market database assessment is widespread in the developing world where, while the informal housing market plays a significant role in the city economy, local planning and housing institutions struggle to collect data for this market segment. Nevertheless, since the sample was very large and contained all the housing units developed under this category in Bogotá between 2000 and 2004, it was considered to be a good data source for the purpose of this research. It also eliminated the uncertainty of a stochastic process which would be present in the analysis of only a pooled sample and not a complete housing market. A more detailed discussion about the existing data bases available at the time this research was conducted can be found in Munoz-Raskin's work for Columbia University (Munoz-Raskin, 2006).

The analysis focused on the effects of Transmilenio on the properties that are within a 10 min walking distance of the system. This distance, or a half mile walk, is the generally accepted standard for walkability before it begins to become burdensome for most people. The areas under analysis are those that fall within the walking distance of the Transmilenio system implemented as of 2004. Consequently, the areas within a 10 min walking distance hinterland to the Norte-Quito-Sur and Suba Transmilenio expansions were not analyzed, since they were opened after 2004. Thus, the area under analysis was (see Fig. 2):

- trunk lines: Avenida Caracas, Calle 80, Autopista Norte, and Avenida Jiménez and Avenida Americas;
- feeder lines: Portal Calle 80 and Usme, Portal Norte, Portal Tunal and Portal Americas.

The properties considered under the area of influence for this study were those that fall within a catchment area of a 10 min walking distance from the BRT (see Figs. 3 and 4). Assuming a 4.392 km/h average walking speed (Knoblauch et al., 1996), a

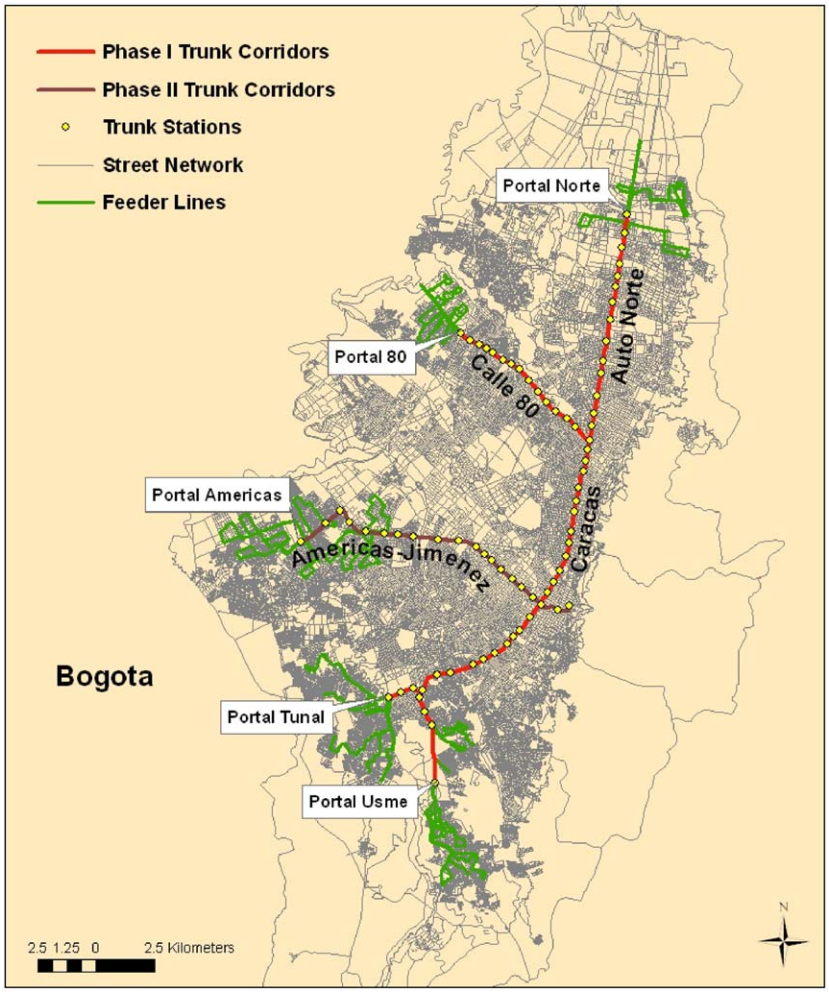

Fig. 2. Transmilenio trunk corridors and feeders used in this research. Data source: elaborated with data from DAPD and Transmilenio S.A.

10 min walk would represent 822 meters. Spatial analysis was conducted using Geographic Information Systems (GIS) to calculate the distance to the system for all the properties within a 10 min walk to BRT. Walking distances were measured with the straight line distance from each property to the closest trunk station or feeder line. For the purposes of this analysis, it was assumed that the difference between the walking distance and the straight line distance was negligible.

4.3. Variables

The variables used to estimate the hedonic price model are described in the Table 1. The dependent variable *price*, representing the residential property value in Colombian Pesos per square meter is deflated using the Housing Price Index for Bogotá to year 2000 constant Colombian Pesos, provided by the Colombia National Department of Planning. The explanatory variables correspond to location, development and physical, market and socio-economic characteristics of a given housing unit. The hedonic model was weighted with the variable *units* so as to consider the greater relative importance of each development according to the number of units that it contains. It is important to keep in mind that socio-economic stratification is a tool used by the Colombian Government and its localities to classify city areas and residential properties. It takes into account the household income levels and availability of public services, among other indicators. This stratification is widely used for household, taxing and service subsidization policies since it more closely resembles the socio-economic conditions of a population which is heavily low and middle income. Thus, for the purpose of this study, Colombian socio-economic stratification is a better indicator of socio-economic conditions than income distribution quintiles that might have been used in other hedonic modeling studies internationally.

This research used socio-economic stratum of the area where the property is located and year the development entered the market as best available proxies for the status and housing quality attributes predicated as relevant by the quality-status theory (Huu Phe and Wakely, 2000). While there still are omitted variables that cannot be quantified in this analysis such as crime rates, quality of schools or parkland, this approach was the best possible for conducting a cost-effective urban economic analysis in the developing country context of Bogotá. Thus, the use of other data bases is encouraged for further research so as to evaluate the effects of proximity to BRT systems on the second hand and informal markets. While it may be very challenging to find meaningful, complete data sets for studies conducted in developing countries, it could be meaningful to add explanatory variables to the hedonic model if possible, such as additional socio-economic factors of the area, macroeconomic considerations or characteristics of the transportation system

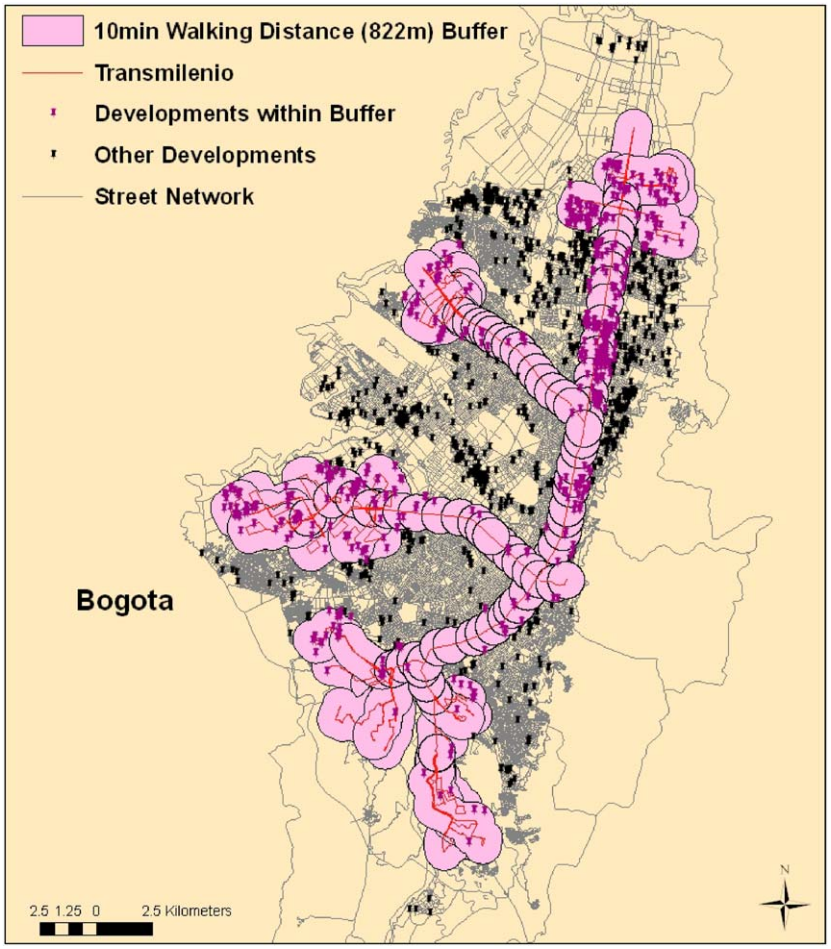

Fig. 3. Residential developments used in this research within 10 min walking distance of Transmilenio (2000–2004). Data source: elaborated with data from DAPD, SCV and Transmilenio S.A.

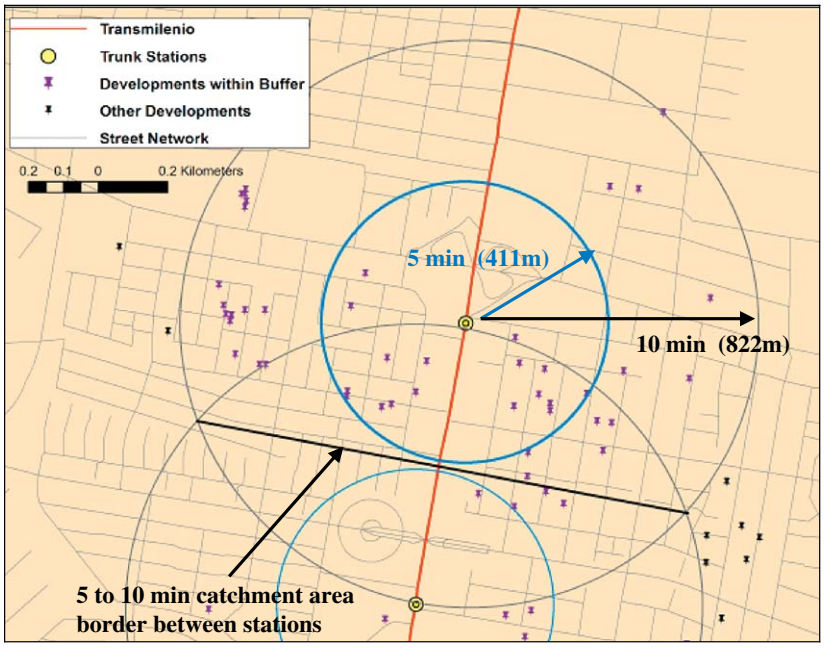

Fig. 4. Five and ten minute catchment areas of two generic stations.

(accessibility indicators, proximity to business districts, existence of alternative transportation modes and their quality, frequency of transportation services), in order to have a more profound analysis. Nevertheless, as stated by Redfearn, gathering the "complete" list of relevant variables is generally not feasible (Redfearn, 2007).

Table 1
Hedonic model variable definition.

Variable	Description	Mean	Std. dev.
Dependent variable			
Price	Residential property value price (Colombian Pesos/square meter)	1 013 757	559 474.4
Lprice	Logged variable of residential property value price (Colombian Pesos/square meter)		
Location attributes			
System_0_10	Property within a 10 min walk to BRT	56.38%	
Trunk_0_10	Property within a 10 min walk to a trunk line station	21.80%	
Trunk_0_5	Property within a 5 min walk to a trunk line station	10.63%	
Trunk_5_10	Property within a 5–10 min walk to a trunk line station	11.17%	
Feeder_0_10	Property within a 10 min walk to a feeder line	34.58%	
Feeder_0_5	Property within a 5 min walk to a feeder line	26.69%	
Feeder_5_10	Property within a 5–10 min to a feeder line	7.89%	
T_autop	Property within a 10 min walk to a Autopista Norte station	10.77%	
Year_t_autop	Product of the variables year and t_autop		
Year_t_autop _0_5	Product of the variables year_t_autop and trunk_0_5		
Year_t_autop _5_10	Product of the variables year_t_autop and trunk_5_10		
F_norte	Property within a 10 min walk to a Portal Norte feeder line	7.89%	
Year_f_norte	Product of the variables year and t_autop		
Year_f_norte_0_5	Product of the variables year_f_norte and feeder_0_5		
Year_ f_norte _5_10	Product of the variables year_f_norte and trunk_5_10		
Development and property attributes			
Size	Average size of property in the development (square meter)	87.19	63.01
Units	Number of units in the development	87.42	110.72
Typ_ap	Apartments development	67.75%	
Typ_ho	Houses development	31.37%	
Typ_lo	Lots development	0.86%	
Year	Year of development	2003.47	1.29
Year_0	Property developed in 2000	10.19%	
Year_1	Property developed in 2001	12.90%	
Year_2	Property developed in 2002	23.81%	
Year_3	Property developed in 2003	25.61%	
Year_4	Property developed in 2004	27.49%	
Socio-economic attributes			
Strat_12	Property located in strata 1 or 2 areas (low-low and low)	19.46%	
Strat_34	Property located in strata 3 or 4 areas (medium-low and medium)	54.18%	
Strat_56	Property located in strata 5 or 6 areas (medium-high and high)	26.35%	

5. Results

The results of the hedonic models showed that there were variations in the average property value of housing across different subsystems (trunk corridors, feeder lines), across different walking distances to the system, across different socio-economic strata housing markets (low, middle and high-income) and across time.

5.1. Transmilenio catchment areas vs. Rest of Bogotá

The calculation was conducted through a cross section multiple regression analysis that assessed, holding all other independent variables in the model constant, the premium or discount in value of the square meter of the properties within a 10 min walk from the BRT. The analysis was conducted both with log-level and level-level approaches for three different models. In these models, each coefficient β_i for a dummy variable i reflects the average premium or discount for the value of the square meter of a property that satisfies the condition that defines the dummy variable. Results are shown in Table 2.

Model 1 compared the value of the properties that fell within walking distance to Transmilenio to the value of the properties elsewhere in Bogotá. The results showed that new properties that fell in the 10 min walking proximity of Transmilenio (*system_0_10*) were, on average, offered at a 4.5% lower price than properties elsewhere in Bogotá. This could be explained by the fact that Transmilenio was implemented under a political decision to locate it along existing major urban transport corridors that were located in areas that mainly corresponded to low and middle income strata, where, on average, the housing market offers lower prices. Thus, no causality between the location of Transmilenio and property values is claimed based on the results of this model.

The value of proximity to Transmilenio was, however, not uniform across different subsystems, as reflected in results for Model 2. The properties that were in a 10 min walk to a trunk station *(trunk_0_10)* and feeder lines *(feeder_0_10)* were valued, respectively, an average 2.8% and 6.6% less than the properties elsewhere in the city. Thus, the properties that were in the 10 min walk to the trunk stations were valued, on average, 4.8% higher than the properties that fell in the 10 min walking distance to the feeder lines. This price differential is consistent with the fact that the trunk corridors cut through areas that are of all socio-economic strata, while the feeder lines were usually located in the low and middle income areas of the city. Furthermore, these results show that feeder lines tended to be located in peripheral areas of the city where land was usually valued less. In these areas, developable land would tend to be less costly, providing an opportunity for more development of housing that was more affordable for the low and middle-income people.

Finally, the relation of proximity to BRT and property values across different walking distances was analyzed in Model 3. The analysis focused on the differentiation of the 0–5 min walk (immediate proximity), and the five-to-10 min walk. The results showed that new properties in the immediate proximity of feeder lines *(feeder_0_5)* showed value premiums of 8.7% compared to those in the five-to-ten walking distance *(feeder_5_10)*. Therefore,

Table 2
Spatial hedonic Models 1, 2 and 3.

	Model 1 (*N*=130 692) Level-level		Log-level		**Model 2** (*N*=130 692) Level-level		Log-level		**Model 3** (*N*=130 692) Level-level		Log-level	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
constant	412896.60	4219.29	13.09	0.0049	−3429.87	8439.69	13.09	0.0050	419041.50	4398.61	13.09	0.0050
Location attributes												
system_0_10	50318.96 ***	2193.38	−0.0520 ***	0.0023								
trunk_0_10					−25544.85 ***	2705.89	−0.0286 ***	0.0031				
feeder_0_10					−65784.87 ***	2349.19	0.0667 ***	0.0024				
trunk_0_5									−47761.94 ***	3133.42	−0.0417 ***	0.0035
trunk_5_10									−7060.30 **	3598.99	−0.0170 ***	0.0045
feeder_0_5									−50664.60 ***	2453.35	−0.0444 ***	0.0025
feeder_5_10									−109705.10 ***	3824.77	−0.1348 ***	0.0044
Development and property attributes												
size	3837.77 ***	55.69	0.0029 ***	0.0000	3827.98 ***	55.53	0.0029 ***	0.0000	3839.87 ***	55.91	0.0029 ***	0.0000
units	−196.17 ***	1.82	−0.0003 ***	0.0000	−195.14 ***	1.83	0.0003 ***	0.0000	−202.71 ***	1.90	−0.0003 ***	0.0000
typ_ap	267856.60 ***	1933.39	0.3909 ***	0.0022	266724.10 ***	1935.78	0.3898 ***	0.0022	267055.30 ***	1936.37	0.3909 ***	0.0022
year_1	24662.34 ***	3350.16	−0.0120 ***	0.0044	29205.17 ***	3382.94	−0.0077 **	0.0045	22992.17 ***	3380.38	−0.0127 ***	0.0044
year_2	59859.32 ***	3126.82	0.0526 ***	0.0038	64303.95 ***	3150.49	0.0568 ***	0.0038	51997.67 ***	3341.13	0.0491 ***	0.0042
year_3	46410.17 ***	3589.13	0.0306 ***	0.0040	52367.39 ***	3599.60	0.0362 ***	0.0040	42348.09 ***	3725.55	0.0285 ***	0.0042
year_4	57046.56 ***	3549.23	0.0342 ***	0.0042	64303.56 ***	3590.22	0.0410 ***	0.0042	56700.77 ***	3650.10	0.0360 ***	0.0044
Socio−economic attributes												
strat_34	18196.93 ***	2620.80	0.0444 ***	0.0029	19178.36 ***	2623.78	0.0453 ***	0.0029	16302.37 ***	2618.68	0.0422 ***	0.0029
strat_56	51677.83 ***	3222.41	0.0836 ***	0.0034	51371.81 ***	3218.54	0.0833 ***	0.0034	49867.38 ***	3236.58	0.0828 ***	0.0034
F	9008.75		16297.52		8142.90		15444.71		9686.19		13155.45	
R-squared	0.3344		0.3667		0.3344		0.3676		0.3506		0.3699	
Root MSE	3.60E+05		0.3877		3.60E+05		0.3877		3.50E+05		0.3867	

***, **, and * denote different from zero coefficient statistically significant at the 1%, 5% and 10% (two-tailed test), respectively. Hedonic models tested for homoskedeasticity with the White test, and found to be heteroskedeastic. Thus, the final results were obtained using a robust model (Wooldridge 2003).

the market reflected that people were actually willing to pay more to be in the immediate walking proximity of Transmilenio in exchange for travel time savings and public space improvements. The hedonic modeling for property values of different walking distances to the trunk stations did not present statistically significant results.

5.2. Analysis by socio-economic strata

There are different housing markets depending on the purchasing power of the buyer. In general, properties in the poorest areas offer more affordable prices for low-income people. Thus, they may have a cheaper value than those in the middle-income areas, while the most expensive housing would be correlated to highest income areas. With this assumption, this research considered that it was important to add a new layer of disagreggation and to limit the hedonic model to three different submarkets according to socio-economic strata. The model designed used income-specific versions of Models 2 and 3. The results are shown in Table 3, and the value premium or discount between categories was obtained by calculating the difference between the coefficients β_i for the specific dummy variables.

The analysis of the property value market within walking distance to Transmilenio showed uneven results across socio-economic strata. The low-income housing market showed average 8.0% value discounts for new properties in the immediate walking proximity to trunk stations compared to the properties in the five-to-10 min walking distance. These results showed evidence that, consistent with high elasticity figures for transportation expenses in the low-income households (low-income Bogotanos already spent an average 18% of their household income on transportation, and the elasticity of their transportation expenditure with respect to income is 1.2 (UNC, 2005)), the low-income population housing market was not paying more for housing that provided shorter walks to the BRT system trunk corridors. For many low-income people, it was still worthwhile to use cheaper paratransit in more congested parallel corridors to save the price differential between Transmilenio and paratransit services that offered ticket prices up to 25% less in advertised price. As described earlier in this research, in many cases low-income individuals may use privately-run paratransit services in slower corridors parallel to the BRT ones, since there is a high marginal utility of the savings between the Transmilenio prices and the paratransit private operator prices. Although it cannot be inferred from the results of this model, these findings would be consistent with the fact that, for the low income strata population, Transmilenio is still not completely affordable for the poorest nor does it provide significant travel time savings to counterbalance the cost savings derived from taking longer walks or using cheaper paratransit. Furthermore, findings from this model revealed a negative value of proximity to Transmilenio on housing prices for low-income strata areas that could be attributable to the poorer environmental conditions in the proximity of the main transportation corridors where trunk services operate with impacts such as air pollution, noise or vibrations, or other omitted variables in this model. For the case of low-income housing in the proximity of feeder lines, results are opposite to the results for the trunk lines. Low income housing in the immediate proximity of feeder lines has an average premium of 7.6% with respect to the properties in the five to 10 min walking distance. This market feature could be associated with the fact that feeder lines usually circulate in secondary transportation corridors where the environmental conditions are not as impacted as in the main transportation corridors.

The middle income housing market presented opposite results to those for the low-income market and gave value premiums of 3.1% and 14.9% to the new properties that fell, respectively, in the immediate walking distance to trunk stations and to feeder lines, compared to the 5–10 min walking distance. These value premiums could be related to the greater accessibility, time savings and public space improvements associated with Transmilenio, especially notable in the feeder line catchment area. Therefore, the middle income housing market catered to

Table 3
Spatial hedonic Models 2 and 3 limited to different Socio-Economic Strata.

	Low income (*N*=25 228)				**Middle income** (*N*=70 300)				**High income** (*N*=35 132)			
	Model 2-limited		**Model 3-limited**		**Model 2-limited**		**Model 3-limited**		**Model 2-limited**		**Model 3-limited**	
	Log-level		Log-level		Log-level		Log-level		Log-level		Log-level	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
constant	12.94 ***	0.0132	12.96 ***	0.0140	13.09 ***	0.0053	13.09 ***	0.0051	13.33 ***	0.0286	13.39 ***	0.0113
Location attributes												
trunk_0_10	−0.0487 ***	0.0071			−0.0541 ***	0.0043			0.0123 *	0.0065		
feeder_0_10	−0.1422 ***	0.0065			−0.0366 ***	0.0031			−0.0656 ***	0.0049		
trunk_0_5			−0.0800 ***	0.0079			−0.0354 ***	0.0045			−0.0794 ***	0.0093
trunk_5_10			−0.0036	0.0105			−0.0676 ***	0.0066			0.0705 ***	0.0081
feeder_0_5			−0.1200 ***	0.0061			−0.0053 *	0.0032			−0.0452 ***	0.0054
feeder_5_10			−0.1963 ***	0.0162			−0.1539 ***	0.0048			−0.0957 ***	0.0067
Development and property attributes												
size	0.0032 ***	0.0001	0.0032 ***	0.0001	0.0034 ***	0.0001	0.0035 ***	0.0001	0.0025 ***	0.0001	0.0025 ***	0.0001
units	−0.0001 **	0.0000	−0.0001	0.0000	−0.0003 ***	0.0000	−0.0003 ***	0.0000	−0.0030 ***	0.0000	0.0004 ***	0.0000
typ_ap	0.4562 ***	0.0058	0.4682 ***	0.0069	0.3784 ***	0.0276	0.3782 ***	0.0272	0.3744 ***	0.0244	0.3764 ***	0.0046
year_1	0.0955 ***	0.0092	0.0772 ***	0.0099	−0.0092	0.0058	−0.0109 **	0.0056	−0.1497 ***	0.0100	−0.1944 ***	0.0104
year_2	0.1623 ***	0.0100	0.1415 ***	0.0106	0.0325 ***	0.0045	0.0358 ***	0.0047	−0.0058	0.0100	−0.0781 ***	0.0110
year_3	0.0683 ***	0.0090	0.0451 ***	0.0098	0.0746 ***	0.0052	0.0716 ***	0.0053	−0.1128 ***	0.0098	−0.1725 ***	0.0109
year_4	0.1291 ***	0.0120	0.1268 ***	0.0119	0.1030 ***	0.0050	0.1020 ***	0.0051	−0.1484 ***	0.0100	−0.2055 ***	0.0108
F	1850.89		1720.62		22,969.05		19,064.20		2792.55		2311.77	
R-squared	0.3338		0.3361		0.4264		0.4322		0.3216		0.3261	
Root MSE	0.4041		0.4035		0.3652		0.3634		0.4005		0.3992	

***,**, and * denote different from zero coefficient statistically significant at the 1%, 5% and 10% (two-tailed test), respectively. Hedonic models tested for homoskedeasticity with the White test, and found to be heteroskedeastic. Thus, the final results were obtained using a robust model (Wooldridge 2003).

customers that were willing to trade-off between accessibility, travel-time savings and other urban improvements derived from the implementation of Transmilenio by paying for more expensive housing, despite the negative environmental externalities that could be present in the immediate proximity of major transportation corridors.

Finally, the high-income housing market revealed notable average value discounts of 14.9% of the value for the new properties that fell in the immediate walking proximity of the trunk lines, compared with the average value of high-income housing in the 5–10 min walk to the BRT system. This could be attributable to the fact that, as it occurs in many developing country's metropolises, the high-income population preferentially used private vehicles. Proximity to BRT was not reflected in a value premium able to counterbalance the negative effects that high-income people perceived from areas in the proximity to transit stations or main transportation corridors, such as noise, visual impacts and safety issues, among others.

Although research should be done to better understand this market behavior, the high-income housing market might had placed this value discount on the properties that were in the immediate proximity of BRT due to environmental impacts such as air pollution, noise or vibrations associated with the transportation corridors, as mentioned for the other income-level housing markets, as well as for concerns about greater pedestrian traffic that could increase the chances for criminal offense. However, on the other hand, the high-income residential market showed slight value premiums of average 5.0% for properties in the immediate walking proximity to the feeder lines, compared to those within a 5–10 min walk. The interpretation for these specific results could be that this market positively valued the better conditions of public space related to the proximity of Transmilenio feeder, considering that they require a softer infrastructure implementation compared to the trunk corridors, and despite the other nuisances mentioned above.

5.3. Analysis across time for two case study areas

The research analyzed the annual average variation of property values within walking distance to specific Transmilenio catchment areas. It was assumed that the total effect of the implementation of the BRT infrastructure on property values would be captured if the data series had historical observations for at least the following phases: (1) planning and evaluation; (2) design; (3) construction; (4) initial stages of operation; and (5) maturity (considered as three years in operation), with a similar approach to the one used in the *Transecon* report that aimed at assessing the effects of urban transport in different socio-economic indicators in European cities (ITS-BOKU, 2003).

The implementation period of each of the different trunk corridors and feeder lines subsystems was analyzed separately taking into account that the data available for this research only had observations for the period 2000–2004. The research limited its analysis to those subsystems that had observations for all the implementation phases. Hence, for some of the subsystems, the observation period did not include the planning, evaluation phase or maturity phases, since they started operating in 2000 and 2003. The only subsystems that qualified for a complete implementation time frame analysis were the Autopista Norte trunk corridor and Portal Norte feeder lines. These subsystems were opened in 2001 and had approximately three years of operation within the time period of data available for this research.

The hedonic Model 4 used for the evaluation of the variation of property values across time in the walking distance to the Autopista Norte trunk stations and Portal Norte feeder lines was based on a pooled cross sectional data analysis. Data was analyzed through a multiple regression analysis that resembled the equations used in this research so far. In particular, the model controlled for a continuous independent variable for time (*year*) that provided the average annual increase in the value of the square meter of new residential housing developments in the city. In addition, it controlled for interactive terms that were created through the products of locational independent dummy variables and the continuous variable *year* (*year_t_autop, year_t_norte).* The values obtained for the coefficients of the interactive terms represented the additional variation to the average annual increase in property value for the respective catchment areas determined through the coefficient for year. Results are shown in Table 4.

Results for properties within a 10 min walk to the Autopista Norte trunk corridor and to the Portal Norte feeder lines subsystem in the North of Bogotá showed evidence that properties accrued, respectively, a 2.2% and 2.9% average annual increase. This could be considered as evidence that there was an increase in the average residential property values for the properties that fall within walking distance to these subsystems of Transmilenio and that this increase is co-related to the increase of accessibility and public space improvements associated to the implementation of the Transmilenio urban development project.

6. Policy implications and further research

6.1. The middle income housing market gave a value premium to proximity to BRT system

The results of this research showed that the middle income housing market positively valued immediate proximity to the corridors where Transmilenio was located. However, causality should not be interpreted from the results of the cross section hedonic modeling conducted in this research. The BRT system

Table 4
Spatial hedonic Model 4.

Model 4	(*N*=130 692) Log-level	
	Coefficient	Std. error
constant	13.08 ***	0.0414
Location attributes		
f_norte	−0.1502 ***	0.0094
t_autop	−0.1332 ***	0.0216
year_t_autop	0.0220 ***	0.0054
year_t_norte	0.0293 ***	0.0027
Development and property attributes		
size	0.0029 ***	0.0000
units	−0.0003 ***	0.0000
typ_ap	0.3886 ***	0.0022
year	0.0067 ***	0.0010
Socio-economic attributes		
strat_34	0.0432 ***	0.0029
strat_56	0.0840 ***	0.0034
F	14 283.82	
R-squared	0.3654	
Root MSE	0.3881	

***, **, and * denote different from zero coefficient statistically significant at the 1%, 5% and 10% (two-tailed test), respectively. Hedonic models tested for homoskedeasticity with the White test, and found to be heteroskedeastic. Thus, the final results were obtained using a robust model (Wooldridge 2003).

offers affordable ticket prices for the middle-income population and superior travel-time savings and quality of service compared to the previous existing paratransit. Thus, if Transmilenio continues to operate with high operational and quality of service standards, it will continue to work as an alternative for the middle income people and an incentive against their need to have an automobile to alleviate their mobility burdens. The mere reinforcement of the affordable services provided to the middle class in Bogotá through Transmilenio should also be welcomed as a sign of potential strengthening of the economy of the middle-income households.

6.2. Mobility burden of the poorest still not fully solved

In the case of the low income strata population, although 37% of Transmilenio users belonged to the low-income stratum and they benefit from the system, the pricing policy for Transmilenio at the time was still not fully affordable for other potential users. Thus, when possible, many low income people might prefer to use alternative slower, but more inexpensive, paratransit to save on transportation expenses, especially if there is no transfer involved in their alternative paratransit journey. In this respect, BRT ticket pricing should provide realistic alternatives to improve the affordability of the transportation accessibility improvements. Access to mobility per se is not the solution for the poorest if they cannot afford the ticket. Policies to alleviate the urban mobility burdens for the poorest sectors of the population must be implemented with complementary measures to provide affordable prices and fare integration with the rest of the non-Transmilenio operators. In this sense, programs such as targeted subsidies to low income population could be studied as measures to foster affordability for the poorest, as is highlighted by Serebrisky et al. (2009) in their work commissioned for the World Bank.

6.3. Potential for low-income housing gentrification

Public transportation is an important policy instrument which can influence the location decision of the poor (Glaeser et al., 2000). Current expansion practices of Transmilenio to new areas of the city should take into account the needs of the different socio-economic strata populations. Since the middle-income market seems to be more sensitive to the accessibility to Transmilenio, showing a notable willingness to pay to be in its proximity, there is a potential for gentrification of the low-income areas in walking proximity of Transmilenio with a shift to middle-income housing. As indicated by a World Bank working paper on conducting impact evaluations in urban transport, property owners might raise rents to a level so high that tenants may need to move to other cheaper locations (World Bank, 2007; Transmilenio, 2007). This situation would probably represent a negative incidence on the poorest households, since the tenants might not be able to benefit directly from the accessibility and urban renovation gains. Whether this would be a problem per se is arguable, but policy makers should carefully understand this potential occurrence and avoid the risk of economic expulsion of the low-income population to ultra peripheral areas and design policies to secure housing affordability within the walking proximity to Transmilenio for low-income users. In addition, further research is recommended to understand if the low-income mobility improved with Transmilenio, for example, through targeted household surveys across formal and informal housing markets, including both home owners and tenants.

6.4. Potential for mitigation of high-income housing value discounts associated to proximity to transport corridors

With regard to the high-income housing market, planning authorities should take into account the value discounts identified that could be associated with immediate proximity to the system. Policies to reduce the nuisances associated to proximity to transportation corridors should be considered to avoid the loss in property values in the immediate proximity of the system. Without aiming at being comprehensive, policy possibilities could try to enhance the perception of safety in those areas by greater policing that would extend from the transit station to the public environment that surrounds the stations (Loukaitou-Sideris et al., 2002), re-zone to allow more convenience stores and other mix-use possibilities in the environs of the transit station, create visual barriers through vegetation, decrease the environmental nuisances such as noise through acoustic barriers and keep up good maintenance and cleanliness to provide a more pleasant environment in the walking proximity of the BRT station. Further research should be done to better understand the reasons related to this value decline and how to best counteract it.

6.5. Price increases associated with Transmilenio implementation must be interpreted as case-specific

The findings on the average annual property value increase of 2.2% for the Autopista Norte and 2.9% for Portal Norte catchment areas are a step forward in the identification of the effects of Transmilenio BRT in property values. However, their specific socio-economic characteristics as areas of predominantly middle and high income housing should be taken into consideration. Results should not be directly extrapolated to the rest of the housing-type, other catchment area submarkets and to other countries. Specific studies conducted in different areas of the City that have different social, economic and environmental characteristics would be instrumental to assess whether those housing markets had a different sensitivity to BRT implementation.

6.6. Land use and transportation policies coordination for spatial efficiency

The efficiency of the transportation improvements of the implementation of Transmilenio would be substantially benefited by the application of appropriate comprehensive integrated land use, zoning and transportation coordinated policies. In Curitiba, Brazil, encouraging higher population densities along the corridors contributed to a more efficient management of the city's spatial resources and optimized the use of the existing BRT mass transit corridors (Cervero, 1998). With the same reasoning, another feasible alternative to catering to the middle-income housing market demand in the walking proximity to Transmilenio is to consider rezoning mechanisms to increase population densities or to provide more developable area. This would also facilitate a reduction in the risk of gentrification of the low-income areas in the proximity of Transmilenio mentioned above, contributing to avoiding greater spatial inefficiencies of the low-income housing allocation. Indeed, transportation and mobility policies should be based on spatial, economic and environmental efficiency goals, and not vice versa.

6.7. Hedonic modeling in urban settings in non-industrialized countries should be approached with caution

The outcome of this paper illustrates the dilemmas that planners and policy makers bear when trying to estimate the

variations of property values as a result of the implementation of mass transit and general transport interventions in urban areas. This research contributes with an unprecedented city-wide hedonic modeling exercise for the determination of the effects of BRT implementation on property values in non-industrialized countries, where market and housing conditions are substantially different to those of developed countries, where the vast majority of similar studies have been carried out.

Data on property values is very difficult to obtain given the opacity of the real estate market, the high cost of data gathering and the lack of comparable comprehensive data sources across the city. Valid data for hedonic modeling requires, at least: (i) territorial coverage of the whole city universe, (ii) a valid time frame that allows for comparison with the counterfactual, (iii) data gathered with a consistent methodology, (iv) sufficient level of data disagregation of the housing developments, and (v) access to the data sources. While the acquisition of sufficient data for hedonic modeling is already difficult in industrialized countries, the likelihood of obtaining it in developing and middle-income countries is exceptional. Furthermore, in these cases, beyond data availability, the research will have to cope with a scenario in which the data will most likely be biased towards the formal market, as is the case of this study. Data for the second hand and informal markets was not considered, because a valid data base with this information does not exist in Bogotá.

In the case of this research, the data source from the DHC was exceptional and provided sufficient information to run the models with fair levels of statistical significance. However, caution should be exercised when basing policy decisions on the results of hedonic modeling. This methodology has attained a wide degree of acceptance in literature as a serviceable methodology for studies about the relation of property values and spatial attributes, but it has some inherent weaknesses since it relies on well functioning markets (World Bank, 2007a, b), which is almost never the case, as described in the methodology section of this research paper.

6.8. *Lessons and opportunities for other cities*

Certain lessons from this research are transferable to other cities in the developing and developed worlds. The effects of the implementation of BRT on property values may have been more notable in the peripheral areas due to a large marginal increase in urban mobility, since there was no other existing mass transit alternative in the city, consistent with the hypothesis previously stated by Rolon (Rolon, 2005). However, cities with existing mass transit may also benefit to a great extent from the extension of their transportation network through BRT to areas that present a great need for mass transportation improvements. Nevertheless, further research on similar studies across more years and additional BRT subsystems, as well as in other cities, would contribute to the understanding of the implications of BRT implementation in the real estate market.

There are additional opportunities offered by an urban project like Transmilenio. The momentum created by the implementation of a project of this magnitude can be used to catalyze urban renovation, environmental and safety improvements, and sense of pride and dignity to the users and to rest of the city dwellers. Also, since BRT can be implemented in a relatively short time frame compared to other heavier infrastructure-based mass transit solutions such as subways, it can be a faster tool to trigger land development and to notably improve urban mobility. All these factors might be reflected in increases in property value as shown in this research.

Planners and policy makers must understand that greater property value increases occur in the housing markets that cater to the users of the transit system, and in the public spaces in its surroundings. Increases in property value are case-specific and BRT – and mass transit systems in general – implementation can also produce value discounts. Finally, it is important to carefully analyze the indirect effects of BRT after a sufficiently long consolidation period and to deeply understand its implications across time and with respect to sustainability.

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Appendix

Exchange rate between Colombian Peso and US Dollar as of June 2005

1 US Dollar=2340.00 Colombian Peso

1 Colombian Peso=0.0004274 US Dollar

Source: www.oanda.com

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