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Value of Accessibility to Bogotá's Bus Rapid Transit System

DANIEL A. RODRÍGUEZ* AND FELIPE TARGA**

**Department of City and Regional Planning, University of North Carolina, Chapel Hill, NC, USA; **Department of Civil and Environmental Engineering, University of Maryland, College Park, MD, USA*

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ABSTRACT *With several successful cases world-wide, bus rapid transit (BRT) has re-emerged as a cost-effective transportation alternative for urban mobility. Despite the resurgence of BRT, there is a world-wide paucity of research examining its ability to spur land development. By estimating spatial hedonic price functions, the paper determines the extent to which access to BRT stations in Bogotá, Colombia, currently are capitalized into land values. Results suggest that for every 5 min of additional walking time to a BRT station, the rental price of a property decreases by between 6.8 and 9.3%, after controlling for structural characteristics, neighbourhood attributes and proximity to the BRT corridor. Evaluated at the average walking time to a BRT station, this effect translates into an elasticity of between –0.16 and –0.22. Although these estimates cannot be attributable directly to the presence of the BRT system because a cross-sectional design is used, they suggest that the land market in Bogotá values access to BRT station locations.*

Introduction

Transportation planners have begun to reconsider the usefulness of enhanced bus services as a cost-effective investment for satisfying growing demands for urban mobility. The re-emergence of bus transit providing high levels of service, under the rubric of bus rapid transit (BRT), is revolutionizing transit systems around the world. BRT involves coordinated improvements in operations, technology, infrastructure and equipment, which provide preferential treatment to buses on urban roadways (US General Accounting Office, 2001, p. 4). Rather than a single concept, BRT encompasses a variety of applications designed to improve the level of service of bus-based mass transit options. Operationally, BRT applications can vary from buses running on an exclusive right-of-way with dedicated stations and preboarding fare payment to buses operating in mixed traffic lanes on city arterials.

Correspondence Address: Daniel A. Rodríguez, Department of City and Regional Planning, 317 New East Hall, CB #3140, University of North Carolina, Chapel Hill, NC 27599–3140, USA. Email: danrod@unc.edu

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Arguably, the BRT application with highest recognition among transportation planners is the provision of an exclusive right-of-way for bus transit coupled with a high-frequency bus service. In Latin America, BRT systems in Curitiba, Brazil, and Bogotá, Colombia, include a network of dedicated lanes designated for exclusive use by large-capacity buses, and expedited boarding and alighting. Other cities, like Sao Paulo in Brazil, Le Mans in France and Liege in Belgium feature BRT functioning along a single line or along multiple lines but without fare integration. According to the US General Accounting Office (2001), more than a dozen cities in the USA are in the process of planning or implementing BRT.

Although BRT has become increasingly popular, some questions about its viability and usefulness as a mass transit option remain. A review of the US General Accounting Office (Hecker, 2003) suggested that local decision-makers and transit officials perceive two main disadvantages of BRT. First, its ability to stimulate economic development may be limited when compared with light and heavy rail systems. The locational rigidity and permanence of the infrastructure of rail-based systems is used to argue their superiority over bus-based services. Accordingly, developers and firms are assumed to be more likely to locate residential, commercial and office developments along a rail line than along a busway. The second perceived disadvantage is that BRT may be disfavoured due to the noise, pollution and negative image often associated with bus services.

Despite several successful cases where BRT has been a cornerstone of an integrated transportation and land-use strategy (e.g. Curitiba, Ottawa in Canada and Brisbane in Australia), there is a paucity of empirical evidence to support or dismiss the relationship between BRT and land development. A recent study commissioned by the World Bank observed, "The impacts of busways on land use and city structure have been little researched" (Halcrow Fox, 2000, p. 164). The same limitation applies to the negative externalities associated with BRT operations. Although a careful examination of BRT impacts is critical for the transportation planning process, potential misperceptions of these impacts can lead to less-than-optimal transportation technology choices, significant facility redesign, construction delays or compensation to affected parties. Thus, systematic studies attempting to isolate proximity-related negative externalities of BRT and the potential for land development due to its accessibility benefits are helpful.

The present study investigates the relationship between accessibility to the location of BRT stations and multifamily apartment rents, while controlling for property attributes and proximity-related negative externalities. Although access to BRT station locations is also expected to be capitalized in retail and office use, focus is on residential properties because such data are more readily available. The study relies on geographical information systems to measure accessibility to BRT lines and the distance to the corridor as a proxy for its deleterious effects. Despite well-known difficulties of estimating welfare measures with hedonic models, consistent estimates of the relationship between accessibility to BRT stations and property values are obtained. The next section summarizes the expected associations between BRT and land markets. The two following sections discuss the hedonic analysis methodology used and the data collected. Results of the empirical analysis and conclusions are provided at the end of the paper.

Bus Rapid Transit (BRT) and Land Values

Over the last 5 years, a mushrooming literature has extolled characteristics of BRT that make it an attractive modal option (Diaz and Schneck, 2000; Levinson *et al.*, 2002; Polzin and Baltes, 2002; Vuchic, 2002). For example, the capital cost of BRT relative to other modes is often cited as a relevant factor in favour of the former (US General Accounting Office, 2001). Other attributes favouring BRT are its implementation and operational flexibility (Jarzab *et al.*, 2002). BRT can be implemented incrementally, allowing for operations before all elements of a given corridor are completed. Similarly, BRT can accommodate changes in demand more easily than light rail transit (LRT). The alignment of BRT also can be modified readily when the location of activities in space changes. For example, if the locus of employment, residences and commercial activities changes in space, so can BRT services. Finally, because BRT vehicles can share many attributes of regular bus services, another aspect of the flexibility of BRT is vehicles' ability to run on and off the right-of-way, as a regular bus or as a BRT vehicle.

Ironically, it is BRT's flexibility that also appears to be one of its main weaknesses. Since BRT infrastructure tends to be less permanent than the infrastructure for LRT, decision-makers and planners question its ability to stimulate land development. The locational rigidity of fixed-track systems and stations tends to be regarded as a commitment to transit service capable of attracting private sector investment to further land and economic development goals (Jarzab *et al.*, 2002; Polzin and Baltes, 2002). However, much of the discussion around the topic of the land development potential of BRT is based on a priori expectations, with limited empirical support provided. Commenting on the impacts on land development along the alignment of several transportation modes, Vuchic (2002) argues

> RB [regular bus], consisting mostly of buses on streets which can be relocated at any time, has no impact. BST [bus semirapid transit] may have an impact if planning is energetically pursued, but LRT has a distinct advantage due to the greater permanence and physical presence of rails and separated ROW [right of way].

Others, however, suggest that conclusions from empirical evidence regarding BRT's ability to induce land development are currently unavailable (Halcrow Fox, 2000; Polzin and Baltes, 2002).

Despite cases like Curitiba, where BRT has been pivotal in the formulation of an integrated transport land-use strategy (Rabinovitch and Leitman, 1996; Smith and Raemaekers, 1998), to the present authors' knowledge, the only evidence to date about the relationship between accessibility to BRT and land values is limited to a handful of studies of bus priority treatments (high-occupancy-vehicle (HOV)-bus lanes) and transitways in North America. Knight and Trygg (1977) examine HOV-bus lanes in Washington, DC, California, Seattle in Washington State, and Florida. They rely on previously published reports, interviews, aerial photographs and other secondary sources available at the time to conclude that exclusive bus lanes incorporated into highways appear to have no impact on either residential or commercial development. More recently, Mullins *et al.* (1990) found that only the BRT in Ottawa, Canada, appears to have some effect on land development in areas surrounding stations. For the rest of the cases analysed (e.g. Houston in Texas, Pittsburgh in Pennsylvania and San Francisco in California), their findings were consistent with those of Knight and Trygg. Finally, a recent hedonic analysis applied to Los Angeles's, CA, first-year with BRT (Cervero and Duncan, 2002b) did not detect any evidence of benefits having accrued to nearby multifamily parcels, although the lack of fixed guideways, the cross-sectional research design and the newness of the service partly explain this result.

Suppositions based on theory have also been made about the proximity-related negative effects of BRT service. According to General Accounting Office interviews with transit agency officials and experts, "communities might not favor BRT, in part because the public often views buses as slow, noisy and polluting" (Hecker, 2003, pp. 13–14). Others have also echoed this concern (Levinson *et al.*, 2002; Vuchic, 2002). While the question about the deleterious effects related to proximity to the right-of-way is an empirical one, Quito's (Ecuador) case suggests that, coupled with technology enhancements such as compressed natural gas and clean diesel, BRTs can provide notable air quality improvements (Wright, 2001).

In summary, BRT is a service concept relying on a combination of right-of-way, vehicle, fare-collection and service-design attributes. It tends to be less expensive than light or heavy rail, can offer similar passenger capacities, and can be implemented incrementally and thus can accommodate dynamic budgetary and demand constraints more readily than fixed track systems. Yet, questions about the usefulness of BRT for influencing urban form remain. Except for the case of Curitiba, where BRT investments go hand in hand with land development strategies, little research performed elsewhere suggests that the land development impacts of BRT are limited or non-existent, although there are concerns about confounding effects. Mostly based on theory, expectations about the impacts of BRT on proximity-related externalities and accessibility (and, by implication, on land development) have been discussed. Animated by the lack of existing research and the increasing relevance of BRTs as transportation mobility solutions for several cities around the world, the present aim is to provide empirical evidence about the nature and magnitude of the value of accessibility to BRT station locations within a particular case.

Hedonic Method Approach

The paper relies on the estimation of hedonic price functions, a technique based on the market for heterogeneous goods developed by Rosen (1974). In Rosen's approach, properties are characterized as a set of complex heterogeneous goods. Each property or good consists of an inseparable bundle of homogeneous attributes that differ in values and characteristics. The underlying theory for the market of heterogeneous goods states that the price of the good is a function of the levels or the value of each attribute in the bundle. The usefulness of the hedonic price functions is that it allows the estimation of the prices of goods that are not explicitly exchanged in observable market transactions. The main assumption of the technique is that implicit prices for each attribute of the good can be inferred by observing an individual's willingness to pay for each unique bundle or set of attributes. In the housing market, these attributes are usually the structural and site characteristics of a property. Attributes of the neighbourhood area, quality of local services and locational attributes such as accessibility to transportation systems or centres of activity are also part of the bundle of attributes.

For the present study, the generic attribute of interest for a property is its accessibility to a BRT station location. Land rent theory, advanced in an urban context by Alonso (1964) and Muth (1969), is commonly used to understand the relationship between accessibility and land values. The core assumption is that households are willing to trade off purchases of accessibility, land area and other attributes. As such, access to a BRT station is expected to provide advantages to certain parcels over others. Because the number of parcels benefiting from access to BRT stations is finite, and assuming that access is a scarce good, households and firms valuing such access in a competitive market are expected to be willing to pay more for properties with good access over other properties, all else being equal. Likewise, it is expected that the effects related to proximity to the right-of-way are negatively capitalized into land values. In summary, despite their potential high correlation, access to BRT stations and the distance from the right-of-way are hypothesized to influence land values in opposite directions: better access should be related to higher property values, and closer proximity to the corridor should be related to lower property values, all else being equal.

The basic empirical relationship to be evaluated is the value of residential properties as a function of property attributes, which typically is of the general form:

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

where V_i is the ith residential 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 for the ith property. The slope of the price function with respect to attributes of interest provides direct empirical evidence that the market value of the parcel reflects in part the presence of such attributes.

An important concern with this approach is that the price function specified cannot allow one to construe the relationship detected between access to BRT and land values as a causal one. For example, if BRT stations were sited in places to which access already was valuable before the presence of the BRT (perhaps due to the presence of mixed land uses), then it could not be concluded that the BRT is responsible for the land value premiums detected. To make more secure statements about the cause of the property value premiums, one must use time-series data and the appropriate modelling of the price function before and after the BRT project. Thus, the cross-sectional approach used herein allows one only to establish associations at the time the data were collected. Given the elusive character of the value of accessibility to BRT, such information is valuable in its own right.

Estimation of hedonic price functions is usually laden with uncertainties, including concern for omitted variables, multicollinearity, choice of functional form for the price function and spatial autocorrelation. Omitting relevant attributes that might be correlated with the attributes of interest may result in biased parameters. Such would be the case if one neglected to account for proximity-related effects in the hedonic price function, because proximity to the corridor is expected to be correlated with accessibility to BRT stations. For the problem of multicollinearity, Leggett and Bockstael (2000) argue that exclusion of highly collinear explanatory variables is appropriate when the variables are not the primary object of study. The present approach to addressing the functional form concerns and the potential spatial association between values observed at different locations (spatial autocorrelation) are covered in the following subsections.

Functional Form

The estimation of the empirical relationship in equation (1) is usually done by means of ordinary least squares (OLS) regression. Questions exist about the use of different forms for the price function. Some evidence suggests simple functional forms such as linear, semilog, double-log and linear Box–Cox forms perform better than more complex ones (Cropper *et al.*, 1988). Other empirical evidence about access to transportation facilities and land values concludes that the best specification for the functional form is a semilog (Garrod and Willis, 1992; Forrest *et al.*, 1996), while most authors have estimated only linear and semilog specifications, and of the two, better results are produced by the semilog specification (Damm *et al.*, 1980; Bajic, 1983; Laakso, 1992; Forrest *et al.*, 1996; Henneberry, 1998).

Because there are no expectations about the functional form for the hedonic price function, three sets of equations are estimated: linear, semilog and double-log functional specification. In the linear specification, the dependent and independent variables are not transformed. The semilog specification transforms the dependent variable logarithmically, but the independent variables remain untransformed. For the double-log specification, the dependent and independent variables are transformed logarithmically when the variables are continuous. Ordinal discrete or dummy variables are not transformed.

Spatial Autocorrelation

Estimation of the functional forms explained above by means of OLS regression is optimal only when a number of assumptions are satisfied. While the hedonic price approach has long proved useful at explaining housing prices based on physical and site-related characteristics, some portion of price variability may remain unexplained. Parts of such unexplained variance may be caused by interdependence among observations attributable to their relative location. If correlation in space among observations is relevant but ignored from the hedonic price model (using simple OLS regression), the assumptions of the OLS regression model will not hold and depending on the characteristics of the autocorrelation the parameters estimated may be biased or inefficient.

The present paper accounts for two different forms of spatial autocorrelation that may occur. One form is related with a lag term on the dependent variable. The other 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. Specifically, the estimated coefficients β_j will be biased under substantive spatial effects, while for spatial error dependence, the coefficients will be inefficient but remain unbiased.

The estimation and diagnostic approach is therefore to estimate the OLS equation for the three forms of the hedonic price function (linear, semilog, double-log). Although it imposes fewer restrictions on the form of the price function, a Box–Cox transformation was not considered as a fourth form of the price function because diagnosing and incorporating spatial autocorrelation become extremely complex (Leggett and Bockstael, 2000). For each of the three equations, the presence and type of spatial autocorrelation are diagnosed by means of Lagrange multiplier tests (Anselin and Getis, 1992) and their robust counterparts (Anselin *et al.*, 1996). Where spatial autocorrelation is detected, maximum likelihood methods are used 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.

Area of Study: Bogotá's BRT System

Bogotá, the capital of Colombia, has approximately 6.5 million inhabitants over 28 153 hectares of urbanized area (Alcaldía Mayor de Bogotá, 2000). This makes the city one of the densest in the world, with approximately 230 people/ha. Despite a 1999 per capita Gross Domestic Product of US$2300, 15% higher than the national average, Bogotá's automobile ownership rate of 110 cars/1000 residents (Ministerio de Transporte, 2002) is low compared with cities of similar size in South America. Although this rate is relatively low, the city is severely affected by mobility problems. By 1999, the average speed during the peak hour on main roads declined to less than 12 km/h (Rodríguez, 2003).

Although several studies prompted by specific transportation projects have been conducted in the last few decades, almost all attempts to provide a sustainable solution for the city's mobility concerns have failed. However, during the last half decade, important mobility and urban development initiatives were undertaken in order to implement a sustainable strategy for the city's transportation system (Sandoval and Hidalgo, 2003). In 1999, when concerned with an oversupply of transit capacity, poor environmental and safety conditions, and decreasing vehicle speeds, the city government invested in an extensive BRT network. The BRT investment was part of a broader, integrated strategy to address mobility challenges, reclaim public spaces for pedestrians and increase access of city residents to green space.

The first phase of the BRT system was planned in 1998, built in 1999–2000 and began operations in December 2000 along two corridors. It was built partly due to 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 an off-board fare collection system. The cost of the first phase of the system was approximately US$5 million/km (Consejo Nacional de Política Económica y Social, 2000). System extensions are planned over the next 13 years, when a 388-km BRT system will be completed. This network is expected to cover 80% of the daily transit trips in the city.

With a flat fare of Col 1000 pesos at the time of writing (= US$0.36, in 2003 dollars), revenues are sufficient for the participating private bus companies to be profitable. Ridership figures show that the BRT system currently carries approximately 800 000 one-way trips/day over 42.5 km of exclusive busways. These ridership figures suggest that TransMilenio effectively carries more travellers than the entire mass transit system of many large cities around the world (International Energy Agency, 2002). The uniqueness of Bogotá's case hinges on the transformation of a busway corridor with severe pollution and

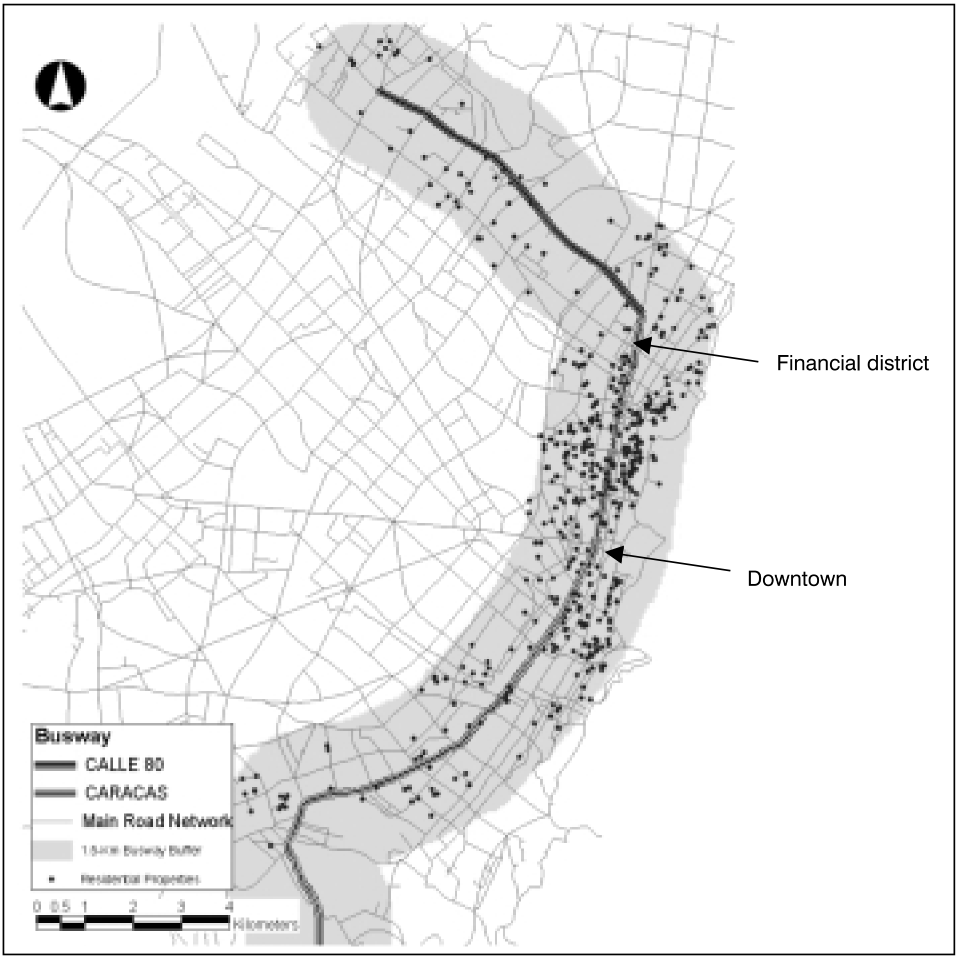

Figure 1. Residential properties in the study area.

safety problems and which is aesthetically displeasing into a new BRT system with significantly lower travel times, lower noise and fewer greenhouse gas emissions.

Data Description

Rather than focusing on the entire metropolitan area, the data collection process for the present study began with the selection of a 1.5-km buffer area around two main corridors of the TransMilenio system at that time (Figure 1). Contemporaneous information on various geographical, demographic, social, land use, housing, education, crime, transportation service and environmental characteristics were collected at different geographical levels, as available. This process required that data be collected from a variety of public and private organizations, including the Departamento Administrativo Nacional de Estadística (DANE), the Centro Interdisciplinario de Estudios Regionales (CIDER) at the Universidad de los Andes, TransMilenio, and Bogotá's Planning and Police Departments.

Multifamily residential properties within the buffer area were identified through field-visual inspection of 'for rent' signs on the premises and via newspaper classified advertisements published from February to April 2002. For the Bogotá housing market, these two sources are the most common methods of advertising residential rental property. The focus on apartments facilitates the consideration of properties that are in close proximity to the corridor, whereas a focus on single-family homes would have made this more difficult. This is because the majority of residences along the corridor are in multifamily as opposed to single-family units. A census of properties immediately adjacent to the corridor conducted in 2001 by TransMilenio suggests that the ratio of multi- to single-family units is almost 2:1. Similarly, although other researchers have used apartments in studies of land values (Asabere and Huffman, 1996; Benjamin and Sirmans, 1996), this approach is valid to the extent that the relationship between access and value in the market for apartments is representative of such a relationship for other land submarkets. Otherwise, future research should focus on examining the relationship for other submarkets identified.

Qualified surveyors conducted telephone interviews about all the properties for rent identified during this period. Therefore, the data represent a census within the BRT impact area defined rather than a statistical sample. The final data consist of 494 multifamily residential properties. The short period within which the data were collected ensures minimal seasonal fluctuations in the real estate market, thereby allowing the use of a cross-sectional approach for the present study.

The dependent variable used for estimating the hedonic price function is the rental price at which the owner or manager is offering the property in the market. Two characteristics of this dependent variable require further explanation. The first is the use of rental price instead of selling price as a proxy for land value. The second refers to the use of asking for rental price instead of the actual or market rental price.

Regarding the use of rental information, an empirical housing rent–land value relationship derived from the standard neoclassical theory of urban housing production was assumed (Muth, 1969). This means that rental prices can be considered an appropriate representation of the land value for housing services. Empirically, several studies of urban amenities and residential land values (Marks, 1984; Guntermann and Norrbin, 1987; McDonald and Osuji, 1995; Jud *et al.*, 1996) have demonstrated that this relationship holds.

The use of asking rental price instead the actual or market rental price as a dependent variable is more problematic. The main concern is that advertised asking price is not directly linked to an equilibrium price, where supply and demand for properties have cleared. Any systematic bias in the difference between asking and market rental price associated with unobservable characteristics of each property will bias the results. Although ways of gathering information on actual selling price or actual rental prices, privacy and security concerns were explored, they prevented the collection of data. This, however, is not the only study where asking rental prices are used as a dependent variable in a hedonic analysis. Other studies using hedonic price models have relied on asking rental price to estimate effects such as the uncertainty of construction quality (Yang, 2001), the prohibition of smoking in vacation properties (Benjamin *et al.*, 2001) and the external effects of agricultural activities (Le Goffe, 2000). Furthermore, other studies relating transit station accessibility to single-family land values (Benjamin and Sirmans, 1996; Cheshire and Sheppard, 1998; Henneberry, 1998) or to commercial property land values (Landis *et al.*, 1995; Cervero and Susantono, 1999) have also relied on asking rental price. The approach assumes that the same influences on asking prices will apply to actual or market prices, i.e. the former is a good proxy for the latter.

Measures of BRT Accessibility

While some studies define accessibility as one's physical ability to reach a station or stop (e.g. Gatzlaff and Smith, 1993; Cervero and Duncan, 2002a, c), others (e.g. Damm *et al.*, 1980; Voith, 1993) define accessibility as the line-haul travel time to particular destinations. Conceptually, one can consider physical accessibility as having local and regional components, with the local component measuring the ease of physical access to a BRT stop or station and the regional component measuring the BRT travel time to where passengers want to go (Dimitriou, 1992). More broadly, accessibility can be viewed in more general terms to include not only travel time and physical access, but also monetary costs, comfort, security, safety, ease of use and the like. Therefore, good physical access to a BRT station is a necessary but not sufficient condition to enjoy the accessibility benefits of BRT.

The majority of studies on the capitalization of transit accessibility benefits in land values reviewed have examined either local or regional physical accessibility, but rarely both. Omitting variables measuring local or regional accessibility from a hedonic price analysis can yield estimates likely to be biased in an unanticipated direction. Other studies have measured local physical accessibility while controlling for regional accessibility by measuring proximity to the labour force (Cervero and Duncan, 2002a, b) or by measuring the average journey-to-work commuting time of the census tract where the property is located (Voith, 1993). The present study measured local and regional physical accessibility explicitly.

Local physical accessibility to BRT is measured as the shortest walking time on the road network from the location of each property to the closest BRT station. This approach is consistent with the notion of access time as a disamenity or perceived inconvenience that individuals try to minimize. Based on traffic engineering and transit planning practice (Transportation Research Board, 2000), walking speeds of 4.39 km/h are assumed. One implicit assumption is that every road is associated with a pavement (sidewalks), which in the authors' view is not problematic since most of Bogotá's streets in built-up areas have pavements (sidewalks). Other access modes to BRT stations, such as by bicycle or car, are either infrequent or irrelevant given there are no integrated facilities for intermodal transfers.

Three measures of regional accessibility capture the line-haul travel time from each station to pole attractors of activities along the BRT. For each property, the line-haul travel time from each property's closest BRT station to three activity centres was calculated using travel speeds provided by TransMilenio. The first activity centre is the financial district or central business district (CBD), the second is the city's downtown (Figure 1), while the third activity attractor is a weighted index of travel time to all stations of the BRT system. The latter is calculated as the line-haul travel time from each BRT station to every other BRT station, weighed by the number of people travelling between each pair of stations. In this way, the third measure captures accessibility to the centre of gravity of activity along the BRT and overcomes many limitations of using merely distance to the CBD to represent accessibility (Wadell *et al.*, 1993). Furthermore, these three measures of regional access are consistent with the broad definition of access as the ability to reach potential or realized activity centres.

Proximity Effects

A feature of this study is the potential for isolating the current implied value of local and regional physical accessibility from the expected discounts related to proximity the corridor. The Euclidean distance from each property to the busway right-of-way is used as a measure of proximity-related effects, such as noise and air pollution. Because the two BRT corridors in Bogotá also have parallel lanes used by automobiles and delivery trucks, the present measure singly controls for the proximity-related effects of all traffic in the corridor, not only the BRT. Given the small distance between busway stations (500 m on average), a high correlation between measures of access to stations and proximity to the corridor is expected. This correlation might influence the estimated significance of the parameters, creating the risk of finding that certain parameters are not statistically significant. However, it is a worthwhile risk since inclusion of these collinear explanatory variables is both theoretically justifiable and the primary object of interest for this study.

Other Control Variables

Consistent with theory and prior research, several structural and locational attributes, or their proxies, are control for that can influence the market value of a property. For structural attributes, usable living area (m^2), number of bedrooms, number of bathrooms, and a dummy variable indicating if the property has both living and dining room areas are included. A dummy variable indicating if the property is less than 10 years old is used as a proxy for structural quality.

Most of the measures of neighbourhood attributes, except where noted, rely on information provided by DANE for 1998 aggregated at the TransMilenio analysis zone. A total of 635 zones are available for the city of Bogotá, with the average area of a zone being 2.73 km^2. The process of calculating neighbourhood attributes involved linking each property to the zone where it is located. Because in some cases a property is on the borderline of two or more analysis zones, a buffer area of 250 m was created around each residential property. For each property, the value of the neighbourhood attributes was calculated as the average of the attributes of zones contained within the buffer area, weighed by the percentage of the buffer area corresponding to each zone.

The neighbourhood attributes measured included economic characteristics, population and employment densities, land-use types, and crime information (measured at a more aggregate level). Economic characteristics include the percentage of residents in the analysis zone living under extreme poverty conditions as defined by DANE, and the socio-economic stratum of the analysis zone (1–6). Because the latter determines the cost of public services (power, water, sewage and rubbish collection) paid by each property dweller, the information of the zone where each property is located was used without the weighing scheme described above.

Gross population density was measured in thousands of residents/km^2, whereas two measures of employment density were used. The first measure of employment density was thousands of agricultural and manufacturing jobs/km^2, as reported by DANE. The second measure of employment density measures was thousands of jobs in the service sector and in public institutions/km^2. Land use variables include the percentage of the built-up area dedicated to different uses (commercial, residential, office). Neighbourhood safety, a proxy for police coverage and other neighbourhood amenities, was measured as the number of break-ins to residential properties, the number of thefts and the number of homicides, each measured per 1000 people for 2001.

Two other variables were used to control for systematic differences among the properties examined. The first determines if the source of the rental information was the classified newspapers advertisements relative to the on site 'for rent' sign (DATA). The expense of placing a newspaper advertisement was expected to be an indicator of higher asking rent. Similarly, a dummy variable was used to indicate the BRT corridor to which each property was closest (BUSWAY). This dummy variable controls for any systematic differences between the two corridors, such as real estate market differences or the presence of a bicycle path in the median of the Calle 80 corridor.

Finally, in most hedonic price models, municipality-level attributes such as quality of the educational system, municipal tax rates or access to recreation areas were included in the price function because they represent a significant factor in influencing property prices. Neither school quality nor property tax rates vary across the study area. However, accessibility to public areas of recreation, such as parks and bicycle ways, is a confounding variable that is not observed directly. With the data, one could calculate the proportion of land within each zone that is not developed, the net of roads and other infrastructure as a surrogate for access to recreation areas. Model results suggested that the coefficient for this variable was not statistically significant and therefore, in the interest of model parsimony, it was not included in the model. Table 1 shows a description of the variables and the summary statistics of the data described above.

Results

The null hypothesis that there is no spatial autocorrelation in the residuals can be rejected at a 95% confidence level using likelihood ratio tests (Anselin, 1993) for the semi- and double-log models. For these two models, diagnostic tests suggested that a spatial error model specification was the preferred way to account for spatial autocorrelation. This means that the OLS estimates are not efficient. As a result, the spatial autocorrelation in these two specifications is accounted for by estimating a model that can be expressed as a combination of equation (1) and a spatial autoregressive model in the error term ε. Formally, the error in equation (1) is modelled as follows:

$$\varepsilon_i = \lambda_i W_i \varepsilon + \xi_i, \qquad (2)$$

where W_i is a spatial weights vector defining the contiguity between observation i and all other observations in space, ξ_i is the error term assumed to be uncorrelated with the error for other observations and having fixed variance, ε is a vector of error terms for all the non-i sites, and λ_i is a nuisance estimated parameter that filters out the spatial autocorrelation in the error term. The parameters of the spatial error model are estimated using maximum likelihood

Table 1. Description of variables and summary statistics ($n = 494$)

Variable	Definition	Mean	SD[c]	Minimum	Maximum
Measures of value:					
RENT[a]	rent offered price (Col$1 million)	0.5	0.4	0.1	3.5
Structural attributes:					
ULAREA	usable living area (m^2)	77.8	44.1	20.0	350.0
BEDS	number of bedrooms	2.2	1.1	1.0	16.0
BATHS	total number of bathrooms	1.5	0.7	1.0	7.0
LROOM	dummy variable indicating if the property has both a living room and a dining room	5.5%			
AGE	dummy variable indicating if the property is less than 10 years of age (= 1, 0 otherwise)	44.1%			
Neighbourhood attributes:					
STRATUM[b]	socio-economic stratum of area (1–6)	3.0		2.0	6.0
POP_DENS	population density (000s/km^2)	16.0	7.4	3.7	43.9
EMP12_DENS	primary and secondary sector employment density (000 jobs/km^2)	5.6	4.4	0.0	20.5
EMP3_DENS	tertiary sector employment density (000 jobs/km^2)	24.8	24.0	0.0	207.3
COMMER_%	percentage of area dedicated to commercial uses	1.0	4.3	0.0	47.8
RESID_%	percentage of area dedicated to residential uses	0.6	3.9	0.0	31.6
OFFI_%	percentage of area dedicated to office uses	4.8	6.9	0.0	53.5
POVER_%	percentage of area under the line of extreme poverty	0.4	2.2	0.0	18.6
ROB_RES	number of break-ins to residential properties per year and per 1000 residents	0.2	0.1	0.1	0.4

(*Continued*)

Table 1. (Continued)

Variable	Definition	Mean	SD[c]	Minimum	Maximum
ROB_PER	number of thefts to individuals per year per 1000 residents	2.5	1.0	0.7	3.9
HOMICIDES	number of homicides per year per 1000 residents	0.6	0.5	0.2	2.0
BUSWAY	dummy variable indicating if the property is along the Caracas corridor (= 1, 0 = Calle 80 corridor)	87.9%			
Accessibility:					
LOCAL_ACC	walking time from the property to the nearest BRT station (min)	11.8	6.4	1.0	34.5
REG_ACC	travel time from the nearest busway station to the centre of gravity of all BRT destinations from that station, morning peak period (min)	11.8	3.4	8.5	23.9
DIST_CBD	travel time from the nearest station to the CBD (76th street) station (min)	10.2	6.9	0.0	32.7
DIST_DT	travel time from the nearest station to the downtown (13th street) station (min)	9.3	7.1	0.0	32.4
Proximity-related:					
DIST_BUSW	aerial distance from the property to the BRT right of way (km)	0.6	0.4	0.0	1.5
Data source:					
DATA	dummy variable indicating if data were collected by field-visual inspection (= 1, 0 = source is newspaper classifieds)	35.8%			

[a] US$1 = Col$2280 as of 2002 (average for February–April)
[b] = Median is reported
[c] = Standard deviation
Thirty-two missing values (6.5%) from ULAREA were input using the best-subset regression. Twenty-three missing values (4.7%) for the dummy AGE variable were set to the median (noted with the subscript '_d' in Table 2). For each of these two variables, dummy variables were used in the price functions to capture the potential effect of imputing these values

methods and a spatial weight matrix with contiguity defined as the inverse distance between each property and other properties within a 1-km band.

Results in Table 2 show that the three functional form specifications perform well. Model fit is adequate, with an $R^2 = 0.71$ for the linear OLS model and the square correlation for the maximum likelihood-spatial error models ranging from 0.742 for the semilog to 0.749 for the double-log specification. The square correlation statistic is a goodness-of-fit statistic measuring the correlation between predicted and observed values (Anselin and Bera, 1998). Other measures of goodness-of-fit such as the ratio of the variance of predicted values over the variance of observed values for the dependent variable also suggest adequate model fit. The model with best fit is the maximum likelihood-spatial error model with heteroskedasticity-corrected error estimates and semilog functional form (Table 2). Thus, interpretation of the results is based on the semilog model, unless stated otherwise.

The estimation and interpretation of the coefficients for physical accessibility is of primary interest here. For residential properties, the coefficients for physical accessibility are expected to be less than zero. This means that properties closer to the BRT station and those closer to activity poles would tend to exhibit higher values, relative to those further away, all else being equal. The coefficients estimated for the physical accessibility variables are negative and significant at a 95% confidence level according to the linear and semilog functional specification, but it is not statistically different from zero for the double-log specification. This suggests that accessibility to BRT station locations currently is capitalized into asking rent prices. The local accessibility parameter in the semilog specification suggests a monthly rental discount of 1.3% for every additional minute from a BRT station (equivalent to 6.7% for every 5 min from the station), because $\ln(1 + i) = -0.0135$, where i is the percentage increase in question, all else being equal. Evaluated at the mean rental asking price (Table 1), this translates into an elasticity of –0.16. The linear specification suggests that for every 5 min from the stop, asking rent decreases by Col$43 000 (US$15). Evaluated at the mean rental asking price and the mean distance to a stop, the elasticity of price with respect to distance to the closest BRT station suggested by the linear model is –0.22.

Because previous evidence suggested that the premiums on residential property values may vary nonlinearly with distance (Wadell *et al.*, 1993), a quadratic and a logarithmic specification for the measure of local access were tested. However, neither of the models estimated (not shown) exhibited a non-linear relationship between distance and property values. This may be the result of the explicit inclusion of a variable measuring distance to the corridor or of the limited buffer area within which properties were identified.

In terms of the three regional accessibility measures, none of the coefficients estimated across the functional forms except one are statistically significant at a 90% confidence level. In retrospect, in a high-density, polycentric urban area like Bogotá, there are not enough reasons to expect regional accessibility benefits to be as relevant as they might be for a monocentric urban area, or for a transportation mode that is CBD oriented, like commuter rail.

While the present authors' interest lies with the current market valuation of physical accessibility to BRT stations, reasonable results with respect to other variables support the present analysis. As hypothesized, the coefficient for the distance to the corridor variable (DIST_BUSW) has the opposite sign of the coefficient for access to BRT stations. The coefficient is statistically significant in

Table 2. ML spatial hedonic error models ($n = 494$)

	Linear			Semilog			Double-log		
	Coefficients	SE	*t*-Statistic	Coefficients	SE	*t*-Statistic	Coefficients	SE	*t*-Statistic
CONSTANT	−0.211	0.210	−1.00	−1.808***	0.258	−7.01	−3.579***	0.346	−10.36
LAMBDA (nuisance)			0.253**	0.115	2.20	0.309**	0.124	2.49	
Structural variables:									
ULAREA^{L}	0.004***	0.001	5.21	0.005***	0.001	7.64	0.359***	0.054	6.61
ULAREA$_{\_d}$	−0.127***	0.047	−2.74	−0.127**	0.054	−2.35	−0.157***	0.058	−2.71
BEDS	−0.002	0.023	−0.10	0.037**	0.018	2.09	0.079	0.049	1.60
BATHS	0.026	0.029	0.90	0.092***	0.029	3.23	0.166***	0.044	3.79
LROOM	0.318***	0.113	2.82	0.090	0.080	1.12	0.274***	0.094	2.91
AGE	0.046**	0.019	2.42	0.084***	0.026	3.26	0.083***	0.025	3.33
AGE$_{\_d}$	−0.135***	0.042	−3.25	−0.142**	0.070	−2.04	−0.165**	0.069	−2.38
Neighbourhood variables:									
STRATUM	0.101***	0.024	4.31	0.120***	0.025	4.80	0.148***	0.023	6.44
POP_DENS^{L}	−0.004**	0.002	−2.03	−0.006*	0.003	−1.80	−0.059	0.053	−1.12
EMP12_DENS^{L}	−0.008***	0.003	−2.82	−0.013***	0.005	−2.88	−0.021	0.016	−1.26
EMP3_DENS^{L}	0.001	0.001	1.57	0.001	0.001	0.75	0.022	0.019	1.17
COMMER_%	0.006	0.005	1.07	0.008	0.006	1.49	0.004	0.006	0.72
RESID_%	0.005	0.006	0.82	−0.002	0.004	−0.45	−0.001	0.005	−0.23
OFFI_%	−0.003*	0.002	−1.66	−0.005**	0.002	−2.22	−0.004*	0.002	−1.72
POVER_%	−0.004	0.005	−0.82	−0.010	0.007	−1.39	−0.010	0.008	−1.28
ROB_RES^{L}	−0.421**	0.188	−2.24	−0.805***	0.295	−2.72	−0.155***	0.058	−2.67
ROB_PER^{L}	0.066***	0.014	4.63	0.132***	0.020	6.56	0.364***	0.055	6.68
HOMICIDES^{L}	−0.033	0.036	−0.91	−0.122*	0.070	−1.74	−0.131***	0.049	−2.67
BUSWAY	−0.021	0.067	−0.31	−0.055	0.094	−0.59	−0.032	0.057	−0.56

Table 2. (Continued)

	Linear			Semilog			Double-log		
	Coefficients	SE	*t*-Statistic	Coefficients	SE	*t*-Statistic	Coefficients	SE	*t*-Statistic
Accessibility variables:									
LOCAL_ACC^{L}	–0.009**	0.004	–2.00	–0.014**	0.006	–2.39	0.002	0.004	0.42
REG_ACC^{L}	–0.001	0.007	–0.16	0.009	0.009	0.99	0.008	0.046	0.17
DIST_CBD^{L}	0.000	0.003	0.06	–0.009*	0.005	–1.63	–0.004	0.007	–0.53
DIST_DT^{L}	0.002	0.005	0.39	–0.005	0.007	–0.65	0.005	0.004	1.25
Proximity variable:									
DIST_BUSW^{L}	0.178***	0.069	2.59	0.283***	0.097	2.92	0.022	0.037	0.59
Data source:									
DATA	–0.023	0.019	–1.21	–0.004	0.024	–0.15	–0.004	0.024	–0.16
Goodness of fit:									
Variance ratio (R^2 for OLS)	0.706		0.752		0.749				
Square correlation			0.742		0.732				
Log likelihood			–14.878		–21.986				

***, ** and * = Coefficient significantly different from zero at the 1, 5 and 10% levels of significance (two-tailed test), respectively. Coefficients for variables in **bold** are adjusted for interpretation according to Kennedy (1981) in the semi- and double-log functional specifications. The spatial weights matrix for the spatial error model is row-standardized and based on the inverse distance for observations within a 1-km distance band. Standard errors (SE) are corrected for heteroskedasticity as suggested by White (1980). The superscript 'L' next to a variable denotes that the variable was transformed logarithmically in the double-log model the linear and semilog specifications at a 99% confidence level. As distance from the corridor increases, property values increase, all else being equal. The coefficient in the semilog equation suggests that for every 0.1 km from the BRT right-of-way, monthly rental asking price increases by 3.3%, which evaluated at the mean asking price translates into an elasticity of 0.19. The coefficient estimated with the linear functional form shows that for every 0.1 km from the right-of-way, asking price increased by Col$176 000 (US$77). Also evaluated at the variable's means, this translates into an elasticity of 0.21. Tests of non-linearity of this relationship were rejected at standard levels of confidence.

With mixed traffic operating parallel to the BRT corridor, and due to the cross-sectional research design, readers should be cautioned against interpreting this result as the proximity-related impacts of BRT on property values. They should be interpreted as empirical evidence of the joint contribution of proximity to the corridor, which comprises BRT and mixed traffic lanes. As such, the impacts cannot be attributed directly to BRT operations. In other cities, such as Quito, anecdotal evidence suggests that the BRT in this corridor has had positive proximity-related impacts partly because the pre-BRT environmental conditions of the corridor were very poor.

Coefficients for a socio-economic stratum are positive and significant at a 99% confidence level. Estimated coefficients for variables such as population density and the density of primary and secondary sector employment are statistically significant at 90 and 99% confidence levels, respectively. For land use variables, only the coefficient estimated for the percentage of urbanized area dedicated to office uses (OFFI_%) is statistically significant at a 90% confidence level. Of note are the parameter estimates for crime variables. The sign of the coefficients is as expected for homicide rates and residential break-ins, but the parameter estimated for thefts to individuals (ROB_PER) has an unexpected sign. For this variable, the association is positive, indicating that the higher the number of reported thefts per capita where a property is located, the higher the asking price of a property. Finally, the coefficients for structural attributes tend to have the expected signs, with more living area, newer properties, and a higher number of bathrooms and bedrooms related to higher rental asking prices. The two dummy variables included in the model specifications in order to account for the imputed cases in the usable living area (ULAREA) and age (AGE) were also significant at the 95% confidence level. The interpretation of these coefficients is that properties not reporting area or age systematically had lower asking prices than properties reporting this information.

To compare the estimates with that of prior research for heavy and light rail systems, Table 3 shows selected results for several studies that have also relied on hedonic price functions. Focus is on heavy rail and light rail partly because BRT provides a menu of options that make it comparable with either mode, depending on the technology and operational characteristics selected. In the case of Bogotá, the BRT is likened to a surface heavy rail system. Although comparisons across studies are not valid in a strict sense because the estimates represent a single point in the demand curve for each study area, tentative comparisons can be made in terms of the estimated elasticity of price with respect to accessibility, the percent change in the value of the property given a change in accessibility and the absolute change in property values.

The present elasticity estimates are strikingly similar to Damm *et al.*'s (1980) estimate for multifamily housing for Washington, DC's METRO system.

Table 3. Land value results of selected hedonic price model studies

Reference	Data source	Selected results
Heavy Rail Rapid Transit:		
(Cervero and Duncan, 2002b)	3803 sales of properties in multifamily housing in Los Angeles in 2000	no evidence of appreciable effects
(Lewis-Workman and Brod, 1997)	all recorded single-family property sales (n = 263) within 1.6 km of BART's Pleasant Hill station for 1984–96	premium of US$1578 for every 0.03 km closer to a BART station
(Benjamin and Sirmans, 1996)	250 residential apartment rental prices in Washington, DC, during 1992	premium of 2.4–2.6% for every 0.16 km closer to a METRO station
(Landis *et al.*, 1995)	2359 sales of single-family homes in Alameda and Contra Costa Counties during 1990	premium of US$100–200 per 0.1 km closer to the station
(McDonald and Osuji, 1995)	79 blocks in Chicago during 1980 and 1990	premium of 17% for a location within 0.3 km of a station
(Smith, 1978)	300 new home sales in Chicago for 1971	premium of US$450 for every 0.8 km closer to a rail transit station
(Damm *et al.*, 1980)	286 single-family, 771 multifamily sales from 1969 to 1976 in Washington, DC	dummy variable indicating a location within 0.16 km of a station: elasticities of −0.19 for a multifamily, and between −0.06 and −0.13 for a single family
Light Rail Transit/Trolley Service:		
(Dueker and Bianco, 1999)	Population Census' median house value in Portland between 1980 and 1990	premium of US$2300 for properties within 0.06 km of a MAX station
(Lewis-Workman and Brod, 1997)	Cadastral information for nearly all properties (4170) within 1.6 km of three MAX stations in Portland	premium of US$75 per 0.03 km closer to a station
(Forrest *et al.*, 1996)	795 house sales in Manchester, UK, during 1990	premium ranging from 2.1 to 8.1% depending on the distance to a station
(Cervero and Duncan, 2002c)	1495 sales of properties in multifamily housing in San Diego in 2000	premium for multifamily units ranging from 2 to 6%
(Landis *et al.*, 1995)	134 single-family sales in San Diego during 1990	premium of US$272 for every 0.1 km closer to a station
(Dabinett, 1998)	Sheffield, UK, Supertram	no evidence of appreciable effects
(Al-Mosaind *et al.*, 1993)	235 single-family home sales in Portland during 1988	premium of US$663 per 0.03 km closer to a station
BRT:		
(Cervero and Duncan, 2002b)	3803 sales of properties in multifamily housing in Los Angeles during 2000	no evidence of appreciable effects

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

Translating the present estimates into units of distance instead of walking time, and using the per cent change in property value, the estimates (1.84–2.63%/0.1 km) are similar to what Cervero and Duncan (2002b) estimate for Los Angeles's Blue Line (1–3.5%) and to what Benjamin and Sirmans (1996) estimate for Washington, DC's METRO but slightly lower than what Cervero and Duncan (2002c) estimate for multifamily units for San Diego, CA (4–18%) and what was estimated for the Manchester, UK, Tramlink (2.1–8.1%) (Forrest *et al.*, 1996).

A comparison in terms of absolute changes in property values is more complicated because rental prices rather than selling prices were observed. However, because the selling price of a property can be viewed as the present value of benefits and costs of a property, the estimated monthly accessibility premium (per 0.1 km) over 20 years was discounted using a 10% yearly discount rate in order to determine the sales price premium implied by the estimate. The estimated premium is between US$439 and $653/0.1 km closer to the station, all else being equal, for the semilog and linear functions, respectively. These figures suggest that the value of accessibility for the current study is somewhat higher than what Landis *et al.* (1995) calculated for San Diego and what Lewis-Workman and Brod (1997) calculated for Portland, OR, slightly lower than what Al-Mosaind *et al.* (1993) also estimated for Portland in 1988, and significantly lower than what Dueker and Bianco (1999) estimated for Portland in 1999. What these sets of cautious comparisons with other studies suggest is that the current accessibility premium to Bogotá BRT is within the order of magnitude of those estimated elsewhere for LRT and heavy rail.

Conclusions

After several successful cases world-wide, BRT has re-emerged as a cost-effective transportation alternative for providing urban mobility. Despite the resurgence of BRT, there is a world-wide paucity of research examining its accessibility and proximity-related effects, such as noise and air pollution. A careful examination of these effects is critical because potential misperceptions about such impacts by transportation agencies and property owners can lead to costly misallocations of funds or delays in implementation. Despite cases like Curitiba, Brazil, where a network of busways has formed the core of a well-articulated land use and transport strategy, there is limited evidence about the relationship between land values and BRT access.

Multifamily residential properties and neighbourhood attributes were used to estimate spatial hedonic price functions for the examination of the current valuation of BRT accessibility. Despite high colinearity, the data can discriminate between the positive effect of being closer to a BRT station and the opposite, negative effect related to proximity to the BRT and mixed-traffic corridor. There was evidence that better physical accessibility to BRT station locations is associated with higher asking prices for multifamily residential rental properties. The capitalization effects of local physical accessibility suggest that properties located 5 min closer to stations exhibit premiums between 6.8 and 9.3% in the asking rental price. These estimates translate into an elasticity of between −0.16 and −0.22. These results show that property owners believe that access to BRT station locations is valuable and are hoping that the market will concur. By contrast, physical accessibility to major activity nodes in the metropolitan area was not associated with higher asking prices. To the degree that the accessibility premiums detected in this study are attributable to the BRT, they begin to question prevalent perceptions of planners and transit agency officials about BRT's limited ability to spur development and economic activity (Hecker, 2003). It is possible, however, that such perceptions are based on uncertainty about future accessibility benefits of BRT, which should be a topic of further research.

The estimates of the current value of local accessibility to BRT stations also provide a useful baseline for examining how such accessibility varies as the BRT system expands in the future. The planned expansion of Bogotá's BRT system from a 42.5-km system to one with several hundred kilometres provides a unique opportunity for assessing these changes. As the system grows, the network effects increasingly will make BRT more competitive against other modes such as the private automobile. This will improve overall accessibility and customer value of the system, which should be reflected in the relationship between local accessibility and land values.

Three limitations of the study that should be underscored are the short period that has passed since the system began operations, the authors' use of asking rental price as the dependent variable in the hedonic price function, and the cross-sectional nature of the data. Because the relationship between access and property values is expected to strengthen, the first limitation suggests that the relationship detected may be a conservative estimate. Although other studies (e.g. Damm *et al.*, 1980) have shown that capitalization begins to materialize when such projects are announced, the time frame of the study allows for only for a 2-year period for accessibility to be capitalized in values. The use of the rental market partially mitigates this limitation because it might reflect more readily changes in accessibility than the market of land for sale. Further research can examine how the land market reacts over time to the accessibility induced by the BRT. The second concern is the result of conducting work in an area where access to information on a person's wealth, such as the value of land or the value of rentals, is very limited for safety reasons of renters and property owners.

The third limitation does not allow one to attribute definitively the premium detected to the presence of the BRT. An understanding of the relative land values before the implementation of the BRT, and of other development changes in the intervening period, are necessary to conclude that the BRT caused the variations detected. Further research may determine if the premium detected in fact is the result of a spurious correlation. Likewise, additional research should attempt to isolate the property value discounts due to proximity to BRT traffic from discounts related to proximity to mixed vehicular traffic. This will be helpful when testing perceptions about the deleterious impacts related to BRT operations.

Finally, by focusing on residential land values, the study tackles one part of the expected relationship between accessibility and the land market. Another, arguably more relevant, aspect of the relationship is to examine the association between commercial property values and access to BRT stations. This seems particularly relevant in areas where BRT corridors run along well-developed commercial areas.

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