The Journal of Transport and Land Use http://jtlu.org
Vol. 15 No. 1 [2022] pp. 425–462

# Bus rapid transit impacts on land uses and development over time in Bogotá and Quito

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**Abstract:** Despite the worldwide popularity of bus rapid transit (BRT), empirical evidence of its effects on land uses and development remains limited. This paper examines BRT's impacts on land use and development in Bogotá and Quito, by using a parcel-level difference-in-differences research design. We estimate a propensity score-weighted regression model of parcel development characteristics in treatment and control areas. In Bogotá, although parcels in close proximity to the BRT are subject to fewer changes in terms of development intensity (changes in built-up area) in relation to parcels in the control area, they are more likely to change uses, shifting toward commercial activities. In Quito, the results are mixed; parcels in one BRT corridor are more likely to be subject to redevelopment, but the parcels in a more recent BRT corridor are less likely to be subject to development activity in relation to parcels in the control corridor. Taken together, our results suggest that changes in land use are important but frequently overlooked impacts produced by BRT implementation. Attempts to capture value from mass transit investments should also consider the ancillary planning decisions required to allow changes in land use.

**Article history:**
Received: August 30, 2021
Received in revised form:
January 25, 2022
Accepted: June 14, 2022
Available online: August 5, 2022

## 1 Introduction

The relationship between transport and land development suggests that land rents and density increase when parcels are closer to the main activity nodes within the urban spatial structure (Alonso, 1964; Muth, 1969). Mass transit investments influence the spatial distribution of urban spatial structure attributes such as land rents and building heights due to the accessibility benefits, they provide. This extra density in turn benefits the transit systems. This reciprocal influence between transportation infrastructure and urban development creates opportunities to reshape cities via transportation investments.

The effects of mass transit on land uses and development constitutes a field of research that has been largely explored for rail-based systems but only more recently has begun to examine the impacts of BRT systems. The capacity of BRT to influence the type of land uses and development taking place along transit corridors constitutes an emerging area of research in regions such as Latin America, which is a regional leader in the design and implementation of this type of mass transit system (Vergel Tovar, 2021). Given the rapid growth of BRT systems worldwide and the level of skepticism regarding the urban shaping effects of this type of mass transit system, it becomes more important to understand

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http://dx.doi.org/10.5198/jtlu.2022.1888
ISSN: 1938-7849

The *Journal of Transport and Land Use* is the official journal of the World Society for Transport and Land Use (WSTLUR) and is published and sponsored by the University of Minnesota Center for Transportation Studies.

the impacts on urban development, by looking at mature systems such as those implemented in Latin America.

The majority of studies examining the relationship between BRT and the built environment have focused on the association between access to BRT and property values (Guzman et al., 2021; Rodriguez & Mojica, 2009; Rodriguez & Targa, 2004; Velandia Najarno, 2013). Perhaps this emphasis is due to the requirement of longer periods over which to assess the impacts on land uses change and development by BRT systems. The necessary time window expected for changes in property values usually tends to be shorter than that required to assess development changes resulting from the implementation of transportation investments.

The capacity of BRT to impact urban form and the extent to which these systems can change land uses and development are still the subject of debate (Stokenberga, 2014). Despite the well-documented and remarkable success of Curitiba in shaping the urban environment along BRT corridors (Cervero, 1998; Lindau et al., 2010; Macedo, 2013; Rodriguez & Vergel-Tovar, 2013; Smith & Raemaekers, 1998), there is limited evidence of the extent to which BRT systems can generate or stimulate land development (Cervero & Dai, 2014; Rodriguez et al., 2016; Rodriguez et al., 2018). This is surprising, as more than 171 cities in the world have implemented BRT system routes which carry over a combined total of 33 million passengers per day (BRTDATA.ORG, 2021 ). Robust evidence of the impacts of BRT on development, specifically of changes in the built-up area and in land uses, is needed to further support BRT planning, to quantify the potential for value capture, and to anticipate and manage its neighborhood consequences.

In this paper, we examine the impacts of the development of BRT investments in two early adopters of BRT in Latin America: Bogotá, Colombia and Quito, Ecuador. Bogotá began operational tests of its BRT system in December of 2000 and this system formally began commercial operation in 2001. Quito began commercial operation of its BRT system in 1996 with the "*Trolebus*" corridor; since then, the city has expanded its BRT network with the Ecovia corridor (2002), the "*Corredor Central Norte*" (2005), the "*Corredor Suroriental*" (2010), and the "*Corredor Suroccidental*" (2012). Both cities have implemented BRT in a staged fashion, creating an opportunity to measure the land-use impacts both before and after each stage of BRT implementation. Both are pioneers of BRT systems in Latin America, and implemented their systems based on the experience provided by Curitiba. For comparison purposes of our data analysis, these two cities offered a unique opportunity not only because they have mature BRT systems, but also because they share similarities, such as urban development processes within geographic constraints, and use similar construction technologies for residential and commercial developments. However, their land-use planning tools, public sector characteristics, and land markets dynamics differ, as does the scope of the BRT intervention of each over time.

We extend prior research by focusing on three outcomes that have not been widely examined yet for BRT: 1) changes in land use (for Bogotá), 2) changes in built-up area at the parcel level (for Bogotá and Quito) and 3) changes in new development activity (Quito). These are important because they constitute land owner or developer actions intended to capitalize on the changes to the local BRT, over and above the price changes that have been documented elsewhere (Deng & Nelson, 2011; Nelson & Ganning, 2015; Rodriguez & Mojica, 2009; Rodriguez & Targa, 2004). These outcomes are also more proximal to the physical changes in land development than are changes in property values. We expect these three outcomes to be distinctively different from but correlated with price changes. Another key aspect of our approach is our reliance on longitudinal parcel-level data to estimate the impacts of BRT investment using propensity score-weighted regression models.

In the next section, we summarize the literature on BRT and land development, after which we provide a description of our methodology, our results, and a discussion of these results in the context of prior research and current policy. In the final section, we provide conclusions and emphasize the main takeaways of our research.

## 2 The city-shaping possibilities offered by BRT

While BRT systems have been built rapidly over the past two decades, researchers are still analyzing aspects of how exactly BRT impacts urban environments. Although we focused primarily on the land use and development impacts of BRT, we provide a brief summary of the literature on the impact of BRT on property values for two reasons. First, there is a strong link between changes on property values with changes in land use and development; for example, developers might need to increase the intensity of land developments with greater floor area ratios, or land uses may change in response to incremental increases in land and property values. Second, this literature has been mostly focused on the impact of BRT systems on property values using cross-sectional study designs, and, in some cases, with data analysis of the changes over short periods of time, despite the fact that assessments of land-use changes and land development impacts require longer time windows due to the slower pace of changes in the urban fabric. Thus, the knowledge we have regarding the impacts of BRT on the urban development process began with the study of property value impacts, and have been more recently extended to land use and development changes by building on the previous empirical evidence.

One of the key impacts that has been widely studied is the land value uplift created by BRT investments. A recent review by Stokenberga (2014) summarized the main findings regarding the impacts of BRT on property values. For this manuscript, we began our literature review with articles published since 2014 and focusing on a synthesis of findings, research methods and drawing lessons for future research from selected study attributes (Supplementary Table A1). Taken together, the estimated price impacts of BRT investments range from null to a 20%-30% increase. However, there is great methodological variation between studies, which severely limits the possibility of comparing their findings. Research design has also varied considerably (before and after, with and without controls, quasiexperimental designs), including research methods such as hedonic price models, propensity scores, multilevel models, spatial hedonic pricing, and matching techniches. Different outcomes (property values of commercial, or single family residential, or multifamily residential, built-up area, and land uses), differences in the assessment of those outcomes (e.g., overall selling price, selling price per unit of area, assessed price, or asking rental price), the measurement of the key independent variable of interest (e.g., aerial distance to BRT stop, network distance to the stop, or whether the stop is within a buffer), time since the BRT system's inauguration, and system operating characteristics comprise just some of the many attributes that differ across studies. It is also entirely reasonable to expect impacts to be context-specific, i.e., such impacts may be the result of the local land market, together with planner as well as developer interactions. These differences make it particularly difficult to compare results.

Further, whether the price changes associated with BRT investments translate into different development patterns remains an open question. With higher prices, developers may choose to focus on different real estate markets, to densify, or to change their assigned use of their land (Cervero et al., 2002). Local land-use regulations such as density caps or land-use designations may also impinge or facilitate the potential land development changes (Berke et al., 2006; Cervero et al., 2004; Curtis et al., 2016). Similarly, higher prices may also elevate real estate interest, turning a dormant or stable area into a rapidly changing one (CTOD, 2013).

The reported number of changes in development density around BRT stops has been irregular. There are examples (such as Seoul) in which the floor-area ratios around BRT stops increased even if land uses remained similar, using hedonic price multilevel models (Cervero & Kang, 2011). For Bogotá the evidence is equally equivocal. On the one hand, Bocarejo et al. (2012) focused on population density via an application of a difference in difference regression model with treatment and control groups, finding a significant increase of density in zones served by the BRT, especially those served by feeder routes (Bocarejo et al., 2012). However, they found no increases in terms of built-up area with respect to the intensity of commercial and office uses. On the other hand, two other examinations of the second phase of Bogotá's BRT that considered changes only for the four years following the inauguration of the new BRT line—rather than a before and after analysis—showed that the floor area ratio in BRT areas increased by 7% overall, while control areas saw a 10% increase, (Cervero & Dai, 2014) (Suzuki et al., 2013).

Examinations of BRT-induced changes in land use have also shown heterogeneous impacts. This means that the implementation of a BRT system does not imply that its impacts are identical along its corridors, according to the evidence in the literature. A US study of nine cities found positive development outcomes in areas served by a BRT, wherein new office space and multifamily developments within 0.5 miles of BRT corridors increased from 11.4% to 15.2% since 2008, based on a before and after data analysis (Nelson & Ganning, 2015). In Seoul, significant conversions of residential uses to more intense multifamily uses were more likely within a half kilometer of a BRT station compared to land parcels located further from the stations, using cross sectional data applying hedonic prices multilevel models (Cervero & Kang, 2011). Changes along the BRT corridors in Bogotá, Ahmedabad, and Guangzhou also suggest varying land-use changes in areas served by their mass transit systems, looking at land-use data before and after the BRT corridor changes (Cervero et al., 2017). In Quito, land-use changed from residential to commercial, and the BRT produced greater development intensity within the its influence area, based on a quasiexperimental research design with treatment and control areas (Rodriguez et al., 2016).

In terms of real estate activity, BRT impacts appear to be a function of the local market conditions. In Bogotá, one study reported increments in building permit density around BRT stations of between 16.4% and 24%. In Quito, the number of building permits approved after its BRT inauguration were significantly higher in relation to the control zones (Rodriguez et al., 2016). More broadly, at the neighborhood level, market interest (expressed as recent developments and approved but yet to be built developments) as well as land availability are key determinants of future activity (CTOD, 2013). The following have all been shown to influence development activity: Neighborhood socio-demographic composition elements such as income, education, and the age of the residents; the presence of particular land uses in the neighborhood (e.g., the presence of industrial uses may depress prices while small scale retail uses may raise values); and the availability of public goods such as parks, roads, as well as with safety (Cervero & Landis, 1997a). Other factors that can render parcels more or less attractive for development include neighborhood accessibility (Ratner & Goetz, 2013) and parcel characteristics such as zoning, parcel size, the presence of easements, and proximity to amenities such as parks and transit stops (Dueker & Bianco, 1999).

The literature on BRT-induced changes in land development over time is limited. The quality of our longitudinal research is greater as changes can be more readily attributed to investments in BRT. But, even in cases where longitudinal data can follow changes over time a control area is needed to adjust for secular trends (e.g., Bocarejo et al., 2012; Cervero & Kang, 2011; Rodriguez et al., 2016; Rodriguez & Mojica, 2009; Suzuki et al. 2013). Whether control areas are comparable to intervention areas is not always clear, and the biases that can be introduced when there are systematic differences between control and treatment areas. This situation (where there are systematic differences) includes the potential market linkages that can exist between control and intervention areas, e.g., as one city area is impacted others are too because land markets are connected. Finally, a related concern has to do with when to measure impacts. Most studies have used a fairly narrow window, ranging from 5 years to 10 years. Clearly, it is important to include a time range long enough to allow land markets to react. This is particularly important when outcomes involve permissions and development, which require significant timeframes to materialize.

The unit of analysis at which land development changes are measured is another important source of variation across studies. Although studies pose definitions involving BRT intervention or impact areas and some include control areas, most examine and report results at the area level (Bocarejo et al., 2012; Rodriguez et al., 2016). However, using the parcel as the unit of analysis is compelling because market transactions, permissions, and developer decisions tend to occur at parcel level. Thus, focusing on analyses at this level will likely better represent the geographic unit at which development impacts take place.

Some of the causes that might be associated with the heterogenous impacts described in this literature review can be summarized in three groups. Development intensity may increase in areas where there are development opportunities and vacant land, while population density may be subject to the type of land development and land uses associated with it. Specific and different land-use changes may occur depending on the distance of each land parcel to the BRT station; for example, conversions to higher density residential developments or the emergence of commercial developments are related to the proximity of the land parcel on which they are to be built to the accesibility benefit generated by the station. Real estate activity and land developments are strongly related to the presence of public facilities and parks, proximity to amenities, land availability, neighborhood accessibility and land-use planning regulations.

The emerging evidence suggests that BRT investment is not only associated with property value uplift but also with changes of interest in real estate market, land use, and development intensity. In this paper, we built on the existing evidence by examining parcel-level changes in built-up areas and land uses for areas impacted by the BRT, in relation to parcels located elsewhere. We further explore these land uses in this paper. A recent meta analysis of BRT impacts on land use and property values suggests that estimates vary across studies, but there is a still a gap in the literature regarding a longitudinal analysis of the impacts. The literature concerning property values is far more extensive than the literature focusing on land-use changes and land development (Zhang & Yen, 2020). In this paper, we therefore provide new evidence regarding land use and development changes using parcel-level data in Bogotá and Quito, based on a research design based on a quantitative data analysis approach using methods that seek to promote more studies that will assess longitudinal changes in the urban fabric.

## 3 Urban planning and transportation in Bogotá and Quito

### 3.1 Bogotá

#### 3.1.1 Mass transit network

In the 1980s, the segregated bus lane corridor "*Troncal Caracas*" was built in Bogota along what is considered the backbone arterial road of the city, connecting the North ("*Autopista Norte*" arterial road) with the south (local district of "Usme"). In 1989, the "*Troncal Caracas*" corridor was built with four segregated lanes, two for each direction, allowing private bus operators to address the demand of existing routes along this corridor as well as extending the service further north and south. The "*Troncal Caracas*" formerly functioned as a closed system, with priority given to bus routes operating along the exclusive lanes. Several issues resulted from this experience, including a decrease in the level of service, operational issues, traffic safety, unfriendly design of bus stops and the detection of the absence of a policy to restructure the public transit system in the city (Thomson, 2007).

In the 1990s, in the absence of funding from the National Government of Colombia for the subway project, Bogotá began the process to design a BRT system based on the experiences of Curitiba and Quito. Transportation planners from Bogota traveled to Curitiba and Quito to learn from the experience of these cities which employed segregated bus lane mass transit systems (Ardila, 2004). But the significance of the BRT project in Bogotá relies on the capacity achieved by this high capacity corridors with segregated lanes which demonstrated that a bus-based system was capable of moving a large number of passengers previously only achieved by rail-based systems (Ardila, 2004). The Transmilenio system in Bogotá introduced innovations never seen before on segregated bus lane mass transit systems such as four segregated lanes which significantly increased the capacity of this bus-based system. After the implementation of high-capacity buses (bi-articulated) and express routes (for selected stops), Transmilenio improved the operational capacity of its system. The system was also innovative in terms of the design of stations as well as terminals by including cutting edge urban design features along with contemporary materials; Transmilenio also conducted interventions in public spaces with pedestrian infrastructure as well as facilities around BRT Terminals located at the North, South and West ends of the corridors (Cain et al., 2007). These BRT Terminals (known as "*Portales*" in Bogota) provided transfers to feeder routes serving neighborhoods located close to these terminals thus increasing the serving area of the system. Figure 1 shows the transit network of Bogota.

Currently, the Metro system of Bogotá is under construction. The city planned to build a metro system since the 1980s, but financial and political issues have forced the city to postpone the project several times. The Metro project enjoyed two recent stages of planning and development. First, in 2008, the city began to define a plan for an underground infrastructure, with the designs achieving a stage of prefeasibility in 2012. In 2016, the city began a second stage of development in which an elevated infrastructure took shape due to the uncertainty regarding the excavation process stemming from the first stage in some areas of the city. In 2021, the city began the construction process of its first Metro line, which is expected to be operational in 2027 (METRO BOGOTA, https://www.metrodebogota.gov.co/).

### 3.1.2 Urban planning

Bogota approved its Urban Master Plan in 2000 based on the Law 388 of Territorial Development of 1997. The Urban Master Plan defined regulations in terms of the type of land-use planning framework for different areas of the city (renovation, consolidation, slum upgrading, environmental protection, and conservation). Zonal Planning Units (ZPUs) divided the city and took the form of polygons with development regulations, the definition of which took almost a decade after they began in 2000. In 2004, the city conducted a review and adjustment of the Urban Master Plan, introducing urban economic principles such as agglomeration economies, clusters of activities, and defining centralities within the framework of urban strategic operations. In 2012, the city undertook another review and adjustment process of its Urban Master Plan, a process that aimed to change radically the planning approach by promoting the densification of a large area known as the "expanded downtown." Although the 2012 adjustment was approved by decree, one year later the judicial system nullified the adjustments to the Urban Master Plan because the city's review and adjustment process had not followed the legal framework for that procedure. In 2016, the city presented a new proposal, aiming to define an updated Urban Master Plan; however, the City Council rejected this proposal. By the end of 2021, the city approved by decree a new Urban Master Plan, which will require additional decrees to address issues related to land development and construction procedures (SDP, https://www.sdp.gov.co/micrositios/pot/documentos).

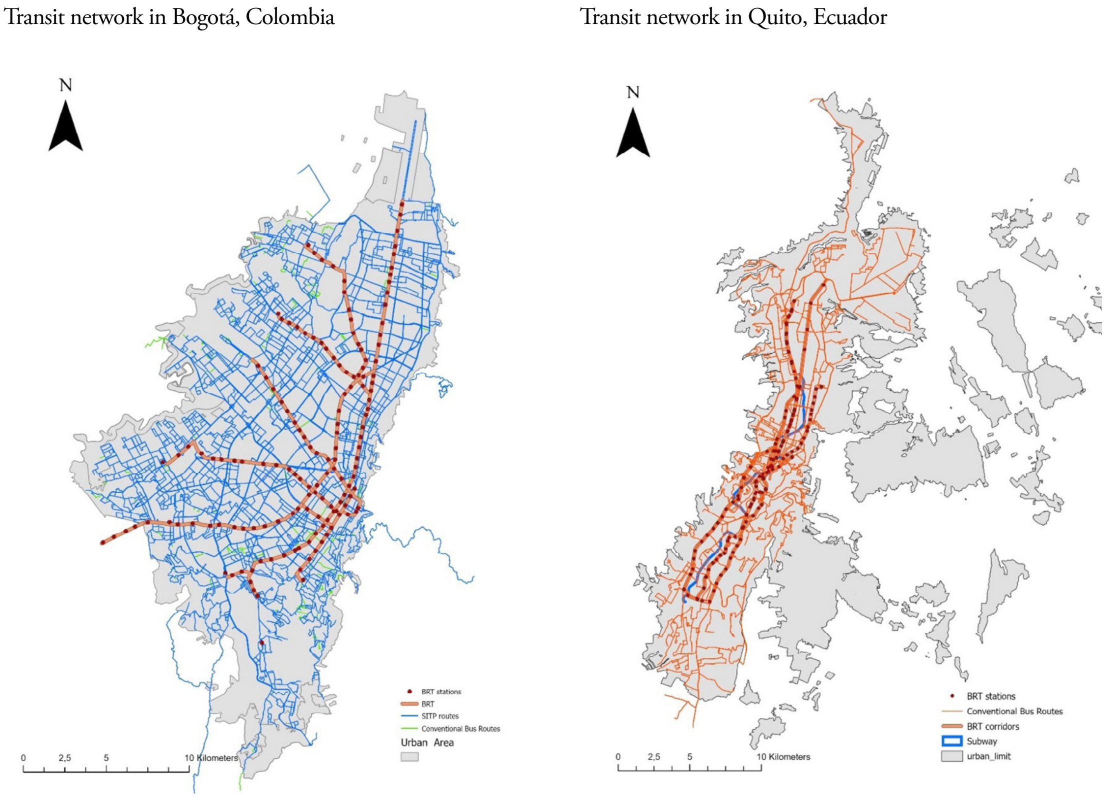
## 3.2 Quito

### 3.2.1 Mass transit network

In the 1990s, Quito (Ecuador) became the first city outside Brazil to implement a BRT system. Quito, implemented a segregated bus lanes system at a large scale based on the Brazilian experience, promoting first the *Trolebus* corridor serving the Historic Center (Mejía-Dugand et al., 2013). Ecuadorian transportation planners (who had received training in Brazil) brought to Ecuador the concept and design of BRT systems. Inspired and influenced by the Brazilian experience, Ecuadorian transportation planners designed and implemented in Quito a segregated lanes system with electric buses known as "*Trolebus*" that began operations in 1996. This system not only improved accessibility in the Historic Center (part of the UNESCO World Heritage List) but also connected the south and the north areas of the city. Both areas have been geographically divided due to the "*Machangara*" River and the "*Panecillo*" Hill next to the Historic Center. The "*Trolebus*" system reduced pollution and noise by using electric buses and incorporated a prepayment boarding system at stations located in the middle of "*Av. 10 de Agosto*" in the North and "*Av. Vicente Maldonado*" at the South of the city. Three bus terminals were constructed as part of this first stage of the "*Trolebus*" system. At the north, the BRT Terminal La Y was built at the end point of "*Av. 10 de Agosto,*" close to the former airport. At the south, the BRT Terminal "*El Recreo*" was built to provide transfers to passengers coming from the South, including the urban expansion area known as "*Quitumbe*". At the geographic center of the city (also close to the Historic Center), the multimodal Terminal "*La Marin*" was built to generate a transit node connecting several services and transportation modes, including those coming from the valleys at the east of the city (Lopez, 2003). In 2013, the city of Quito began the construction process of its Metro system. The construction process required underground work, with special care in the Historic Center area to protect the conservation sites and the Center's Architecture Heritage. The first stage of the construction process focused on the provision of the key transfer stations known as *La Magdalena* and *Labrador.* The second stage included the construction of the underground tunnels, the other stations, and the acquisition of the operations equipment. The infrastructure is now ready, and the city is conducting operational tests, but the system has not opened for commercial operations yet. Figure 1 shows the transit network of Quito.

### 3.2.2 Urban planning

The city of Quito has had different Urban Master Plans. In the beginning of the 1990s, the city developed the RUQ (*Reglamento Urbano de Quito* in Spanish); this plan was approved in 1992, when the "*Trolebus*" project was under review. The RUQ established a mixture of land uses and permitted greater maximum building heights along the main arterial roads of Quito, whether those arterial roads included BRT corridors or not. The RUQ is a land-use planning regulation established prior to the implementation of the BRT corridors. The land-use planning regulation in the city of Quito includes the Historic Center (as stated previously, a UNESCO World Heritage Site) as a special piece of conservation and preservation in the urban master plans. The PUOS (*Plan de Uso y Ocupación del Suelo* in Spanish), adopted in 2005, defined guidelines for the urban development process as well as land-use planning regulations for new developments. In 2012, the city approved the PMOT (Plan *Metropolitano de Ordenamiento Territorial* in Spanish), consolidating the urban spatial structure of the city using a monocentric framework defined by the *Hipercentro*, an area that concentrates a large number of jobs and commercial activities in the city (Quito, 2012). In 2021, the city of Quito approved an updated PUOS, based on the principles established by the new Law of Territorial Planning and Land Uses approved by the National Congress in 2016 (QUITO) (Instituto de la Ciudad2021, https://institutodelaciudad.com.ec/plan-de-uso-y-gestion-de-suelo-2021-2033-del-distrito-metropolitano-de-quito/).


Transit network in Bogotá, Colombia

Transit network in Quito, Ecuador

**Figure 1.** Transit network in Bogota and Quito
Source: (Ecuador, 2021; IDECA, 2021)

## 4 Methodology

We follow a quasi-experimental research design at the parcel level. Parcels are located either in an intervention area (areas with a BRT service) or a control area (areas in which a BRT implementation is planned but a definite announcement has not been made regarding construction). Both intervention areas and control areas are defined by the parcels that are completely or partially within an aerial buffer area of 500 meters along the existing (intervention) or planned (control) BRT corridor. We excluded parcels that overlap the buffer areas of the first and the second phases of the BRT system ("*NQS*," "*Av Americas*," "*Calle 13*") as shown in Figure 2. Our approach differs from that of previous researchers (Rodriguez et al., 2016) in that we measure changes at the parcel level instead several neighborhoods. Parcel level data provides the advantage of observing changes with a higher variation within blocks and neighborhoods, which is a key difference from previous research that measured built-up area, i.e., changes in larger polygons such as urban districts.

Our first study area is Bogotá, the capital of Colombia and its largest city, with a population of 7.2 million inhabitants in an area of 380/km2 (DANE, 2018). Bogotá began the commercial operations of Phase One of its BRT in January of 2001, which included three trunk corridors: "*Av Caracas*" (11.9 km with 14 stations,), "*Autonorte*" (10.3km with 15 stations), and, "*Av Calle 80*" (10.1km with 12 stations). Two main arterial roads in the west of the city, "*Av. Boyaca*" and "*Av. 68,*" were part of the BRT network for the fourth phase of Transmilenio. Currently, "*Av. 68*" is under construction for a new BRT corridor, and "*Av. Boyaca*" has been identified in the new Urban Master Plan as a future mass transit corridor. It is not clear when construction will begin in "*Av. Boyacá*" (Figure 2, left panel).

**BRT corridors (treatment) and arterial roads (controls)**
**Bogotá, Colombia**

BRT corridors (treatment) and arterial roads (controls)
Quito, Ecuador

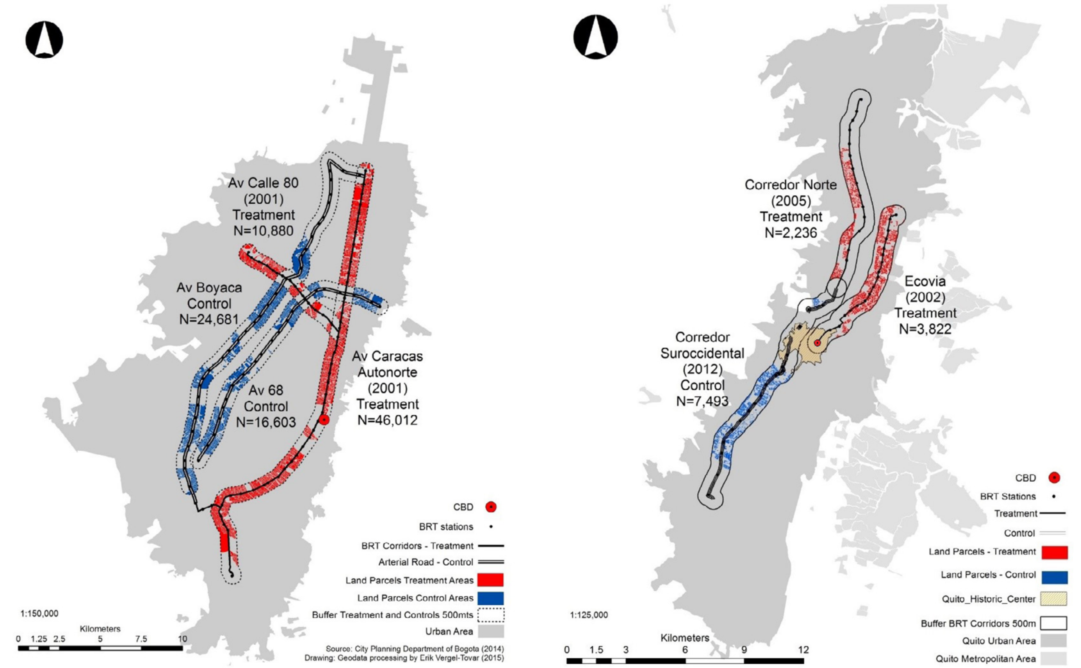


**Figure 2.** Bogota and Quito, treatment and control areas

Source: City Planning Department and Cadaster Department of Bogotá, City Planning Department and Cadaster Department of Quito,

Quito, our second study area, is the capital city of Ecuador, with 2.8 million people inhabiting an area of 372,4/km2 (INEC, 2017). Based on the BRT experience of the city of Curitiba (Brazil), Quito designed and implemented the first phase of its BRT system using electric trolley buses. The Quito BRT system began operations in 1996 along the "*Trolebus*" corridor (14.4 km and 23 stations) connecting the area known as "*La Y*" in the north with the area known as "*El Recreo*" in the South (Figure 2, right panel) and crossing through the city's Historical Center. Additional corridors were added to the network over time. In 2000, the "*Trolebus*" corridor began operations towards the new extension of the corridor towards south, adding 4.72 km and 10 stations to the corridor. In 2008, the same corridor began operation with an extension further south by 2.62 km adding 3 stations, including the BRT Terminal Quitumbe. The "*Ecovia*" corridor began operations in 2002 with an extension of 8.45 km and 17 stations. In 2012, the trunk corridor "*Corredor Suroccidental*" began operations connecting the "C*orredor Norte*" (10.24 km, 18 stations, commercial operations since 2005) with the south of the city at the BRT terminal "*Quitumbe.*" Prior to the BRT service being implemented, the *"Corredor Suroccidental"* was used as a control in our analysis for other corridors that had previously received the BRT service.

In sum, by observing both intervention and control areas before and after the changes, we were able to estimate the effect in both study areas, by comparing the difference of the differences. The intervention areas in Bogotá are "*Avenida Caracas*," "*Av Calle 80*," and "*Autonorte*," while the control areas are "Av Boyaca" and "Av 68" (Figure 2, left panel). In Quito, the intervention areas are located along "*Ecovia*" and "*Corredor Norte*," while the "*Corredor Suroccidental*" is the control area because it only began operations in 2012 (Figure 2, right panel).

### 4.1 Outcomes

We focus on three outcomes: changes in land use (Bogotá), changes in built-up area (Bogotá and Quito), and changes in development activity (Quito). We measure these outcomes at the parcel level by examining the prevailing built-up area and the land use of each parcel over time. In Bogotá, we observe each parcel every year for 13 years (from 2000 to 2013) and in Quito for 10 years (from 2000 to 2010). Given that corridors were implemented at different times in each city, the before and after periods for each corridor are not the same. In Bogotá, the three treatment corridors ("*Avenida Caracas*," "*Av Calle 80*," and "*Autonorte*") were observed 1 year before BRT commercial operations began and for up to 12 years after the intervention. In Quito, the "*Ecovia*" corridor was observed 1 year before and for 8 years after the intervention while the "*Corredor Norte*" was observed 4 years before and for 5 years after the intervention.

### 4.2 Data

In this section, we first describe our data sources for the outcomes and our independent variables of interest. Consistent with our literature review, we focus on parcel-level characteristics and on the neighborhood level physical attributes as well as the market attributes of the neighborhood. A description of our data and its variables, for both cities, appears in Table 1. The data for Bogotá were taken from the City Planning Department, the City Cadaster Department, and the National Statistics Department (DANE). Data for Quito were taken from the City Planning Department, the City Cadaster Department, and the National Statistics Department (INEC). The city cadaster departments of both cities provided the data with confidentiality restricions. In Bogotá, we examined three dependent variables (parcel built-up area, parcels devoted to residential uses, and parcels devoted to commercial uses) and, for Quito, we examined two dependent variables, the built-up area and the presence of new developments (the latter was based on the age of construction for each land parcel; Table 1). We focused on different outcomes for each city based on whether the data was available. We selected built-up area as a dependent variable based on our literature review, following the quantitative data analysis approach used in previous studies . We also focused on commercial and residential land uses in line with the land-use types that we identified in the literature review (Supplementary Table A1).

We measured the distance to the BRT stations (current or future) using GIS, assigning each land parcel to the closest station, which allowed us to define mutually exclusive categories within the distance ranges described in the table. We used the same method to measure the distances to the central business district (Bogotá: "*Av. Calle 26,*" "*Centro Internacional*"; Quito: "*La Marin*" main transportation hub) and to the BRT corridor (current or future). We obtained our land-use data from the Cadaster Department in Bogotá and from the City Planning Department of Quito. We estimated the population density using GIS based on the overlap between blocks and census tract data provided by the City Planning Department of each city. Block size was also measured using GIS.

At the neighborhood level, we calculated the ratio of road space and parks using GIS. In Bogotá, although the land parcel data was collected between 1999 and 2000, that for our independent variables was obtained for 2000. In Quito, we excluded from our analysis the land parcels within the Historic Center. We processed the Quito data set which contained time-varying variables based on the variable indicating the year of construction, which we used to determine the built-up area per year from 2001 to 2010. Parcels without built-up area data were exluded from analysis. Given the elongated nature of Quito, 3,230 treatment parcels located a further 8km north from the CBD were removed from the data set due to the absence of parcels at the same distance range in the control areas. In Bogotá, we included socioeconomic data using the Cadaster Department classification used for cross subsidies schemes for public services (from one to six), thus this variable constitutes a proxy to socioeconomic level.

**Table 1.** Description of variables in Bogotá and Quito

| **Bogota** | | | | **Quito** | | | |
|---|---|---|---|---|---|---|---|
| **Variable** | Definition | Level | Source | Variable | Definition | Level | Source |
| | **Dependent variables** | | | | **Dependent variables** | | |
| **Ln Built-up Area** | Natural logarithm total built-up area in parcel in sqmt between 2000 and 2013 within buffer area | Parcel | Cadaster department | **Ln Built-up area (new developments)** | Natural logarithm of total built-up area in parcel in sqmt of new developments within buffer area between 2001 and 2010; Otherwise=0 | Parcel | Cadaster and City Planning departments |
| **Commercial land use** | Parcel in commercial land uses=1 between 2000 and 2013; otherwise=0 | Parcel | Cadaster department | **New developments** | New development=1 between 2001 and 2010; otherwise=0 | Parcel | Cadaster and City Planning departments |
| **Residential land use** | Parcel in residential land uses=1 between 2000 and 2013; otherwise=0 | Parcel | Cadaster department | | | | |
| | **Independent variables** | | | | **Independent variables** | | |
| **Treatment** | Treatment=1; Control=0 | Parcel | | **Treatment** | Treatment=1; 0=Otherwise | Parcel | |
| | **Location factors of land parcels** | | | | **Location factors of land parcels** | | |
| **Distance BRT Station 1 ≤100 m** | If linear distance of land parcel in meters to current BRT station (treatment) or projected station (control) ≤ 100 meters=1; Otherwise=0 | Parcel | GIS (Transmilenio SA††) | **Distance BRT Station 1 ≤100 m** | If linear distance of land parcel in meters to BRT station (treatment) or projected station (control) ≤ 100 meters=1; Otherwise=0 | Parcel | GIS (EPMTPQ††) |
| **Distance BRT Station 2 >100m ≤200 m** | If linear distance of land parcel in meters to current BRT station (treatment) or projected station (control) > 100 meters and ≤ 200 meters=1; Otherwise=0 | Parcel | GIS (Transmilenio SA††) | **Distance BRT Station 2 >100m ≤200 m** | If linear distance of land parcel in meters to BRT station (treatment) or projected station (control) > 100 meters and ≤ 200 meters=1; Otherwise=0 | Parcel | GIS (EPMTPQ††) |
| **Distance BRT Station 3 >200m ≤300 m** | If linear distance of land parcel in meters to current BRT station (treatment) or projected station (control) > 200 meters and ≤ 300 meters=1; Otherwise=0 | Parcel | GIS (Transmilenio SA††) | **Distance BRT Station 3 >200m ≤300 m** | If linear distance of land parcel in meters to BRT station (treatment) or projected station (control) > 200 meters and ≤ 300 meters=1; Otherwise=0 | Parcel | GIS (EPMTPQ††) |
| **Distance BRT Station 4 >300m ≤400 m** | If linear distance of land parcel in meters to current BRT station (treatment) or projected station (control) > 300 meters and ≤ 400 meters=1; Otherwise=0 | Parcel | GIS (Transmilenio SA††) | **Distance BRT Station 4 >300m ≤400 m** | If linear distance of land parcel in meters to BRT station (treatment) or projected station (control) > 300 meters and ≤ 400 meters=1; Otherwise=0 | Parcel | GIS (EPMTPQ††) |
| **Distance BRT Station 5 >400 m ≤500 m** | If linear distance of land parcel in meters to current BRT station (treatment) or projected station (control) > 400 meters and ≤ 500 meters=1; Otherwise=0 | Parcel | GIS (Transmilenio SA††) | **Distance BRT Station 5 >400 m ≤500 m** | If linear distance of land parcel in meters to BRT station (treatment) or projected station (control) > 400 meters and ≤ 500 meters=1; Otherwise=0 | Parcel | GIS (EPMTPQ††) |
| **Distance BRT Station 6 >500 m** | If linear distance of land parcel in meters to current BRT station (treatment) or projected station (control) > 500 meters; Otherwise=0 | Parcel | GIS **(Transmilenio SA††)** | **Distance BRT Station 6 >500 m** | If linear distance of land parcel in meters to BRT station (treatment) or projected station (control) > 500 meters; Otherwise=0 | Parcel | GIS (EPMTPQ††) |

| Bogota | | | | Quito | | | |
|---|---|---|---|---|---|---|---|
| **Variable** | Definition | Level | Source | Variable | Definition | Level | Source |
| **Ln Distance CBD** | Natural logarithm straight line distance to the International Center (Av. Calle 26) | Parcel | GIS (City planning department) | **Ln Distance CBD** | Natural logarithm straight line distance to the City Center ("*La Marin*" Transportation Hub) | Parcel | GIS (City planning department) |
| **Ln Distance BRT corridor** | Natural logarithm straight line distance to BRT corridor or major arterial road (future BRT corridor in control area) | Parcel | GIS (City planning department, Transmilenio SA††) | **Ln Distance BRT corridor** | Natural logarithm straight line distance to BRT corridor or major arterial road (future BRT corridor in control area) | Parcel | GIS (City planning department, EPMTPQ††) |
| **Land attributes, use and socioeconomic characteristics of land parcels** | | | | **Land attributes, use and socioeconomic characteristics** | | | |
| **Land Uses** | Residential=1; Industrial=2; Commercial=3; Facilities=4; Vacant=5; Other=6; Mixed-use=7 between 2000 and 2013 | Parcel | Cadaster department | **Land Uses** | Residential=1; Mixed=2; Institutional=3; Other=4 according to the PUOS in 2005 | Parcel | Cadaster and City Planning departments |
| **Ln Parcel Area** | Natural logarithm of area of parcel in sqmt within buffer area between 2000 and 2013 | Parcel | GIS (Cadaster department) | **Age of construction** | 2001-2010=1; 1991-2001=2; 1981-1991=3; 1971-1981=4; 1961-1971=5; before 1961=6 | Parcel | Cadaster and City Planning departments |
| **Ln Properties*** | Natural logarithm # properties* within land parcel between 2000 and 2013 | Parcel | Cadaster department | **Ln Parcel Area** | Natural logarithm of land area of parcel in sqmt within buffer area | Parcel | (City Planning departments) |
| **Socioeconomic level***** | Level 1=1; Level 2=2; Level 3=3; Level 4=4; Level 5=5; Level 6=6 between 2000 and 2013 | Parcel | Cadaster department | **Ln Population density** | Natural logarithm of people per hectare at the block level within buffer area in 2001 and 2010 | Block | GIS (City planning department, INEC†††) |
| **Ln Property Value** | Natural logarithm of commercial appraised value between 2000 and 2013 in COP (million) | Parcel | Cadaster department | **Ln Block Size** | Natural logarithm of block size area within buffer area | Block | GIS (City planning department) |
| **Ln Population density** | Natural logarithm of people per hectare at the block level within buffer area in 2000 and 2009 | Block | GIS (City planning department) | | | | |
| **Ln Block Size** | Natural logarithm of block size area in sqmt within buffer area | Block | GIS (City planning department) | | | | |
| **Neighborhood attributes** | | | | **Neighborhood attributes** | | | |
| **Ln Roads ratio** | Natural logarithm total road area per gross neighborhood area in 2000 (total road area excluding blocks in sqmt/neighborhood area in sqmt) | Neighborhood | GIS (City planning department) | **Ln Roads ratio** | Natural logarithm total road area per gross neighborhood area (total road area excluding blocks in sqmt/neighborhood area in sqmt) | Neighborhood | GIS (City planning department) |
| **Ln Parks Ratio** | Natural logarithm total park area per gross neighborhood area in 2000 (total park area in sqmt/neighborhood area in sqmt) | Neighborhood | GIS (City planning department) | **Ln Parks Ratio** | Natural logarithm total park area per gross neighborhood area (total park area in sqmt/neighborhood area in sqmt) | Neighborhood | GIS (City planning department) |

| Bogota | | | | Quito | | | |
|---|---|---|---|---|---|---|---|
| **Variable** | Definition | Level | Source | Variable | Definition | Level | Source |
| **Ln Facilities** Density** | Natural logarithm density of facilities per gross neighborhood area in 2000 (total number of facilities/ neighborhood area in Ha). | Neighborhood | GIS (City planning department) | **Ln Facilities** Density** | Natural logarithm density of facilities per gross neighborhood area (total number of facilities/ neighborhood area in Ha). | Neighborhood | GIS (City planning department) |
| **Built-up area in square meters (completed developments)** | Proportion of total built-up area in sqmts of developments at the neighborhood level per total built sqmts of developments in 2000, 2004, 2009 and 2013. | Neighborhood | DANE††† (Building activity census) | | | | |
| **New built-up area in square meters (started developments)** | Proportion of total new built-up area in sqmts of started developments at the neighborhood level per total new sqmts of developments in 2000, 2004, 2009 and 2013. | Neighborhood | DANE††† (Building activity census) | | | | |
| **Square meters under construction (development in progress)** | Proportion of total sqmts under construction of developments at the neighborhood level per total sqmts under development in 2000, 2004, 2009 and 2013. | Neighborhood | DANE††† (Building activity census) | | | | |

††Transmilenio SA is the Bus Rapid Transit Agency of Bogotá
†††DANE is the National Statistics Agency of Colombia (Departamento Administrativo Nacional de Estadística in Spanish)
*Properties=number of residential units within a land parcel.

†EPMTPQ Public Metropolitan Agency of Passengers of Quito (Empresa Publica Metropolitana de Pasajeros de Quito)
†††INEC National Institute of Statistics of Ecuador
**Facilities: public facilities such as schools, hospitals, temples, libraries, market squares, sports, recreational infrastructure buildings.
***Socioeconomic level data is a categorical variable with six values taking the classification determined by the cadaster department based on the "stratum" concept. This concept classifies land parcels in Colombian cities in six levels to implement cross subsidies schemes for public services that seek to benefit levels one, two and three. Thus, this variable constitutes a proxy to socioeconomic level.

### 4.3 Estimation of propensity scores

We used propensity scores to address the possible bias in our selection of parcels benefiting from BRT in relation to the parcels in our control areas. We followed the approach of Rosenbaum and Rubin (1983) to estimate the probability of land parcels being under treatment using a logistic regression model as a function of our measured covariates (D'Agostino, 1998). This is often termed the propensity score model. (Please see tables A2 and A3 in the supplemental materials for the estimation results for each city.) Covariates were chosen based on their possibility to explain the relationship between parcels and treatment assignment. Given that treatment and control observations are compared based on the descriptive statistics before treatment, we used an estimation of the propensity scores to achieve a balance between the treatment and control groups by using the covariate values before treatment (McCaffrey et al., 2013). The propensity score estimates the probability of land parcels being under treatment with logistic regression models with a group of covariates.

We then used the propensity scores as weights to examine the balance among the covariates between the treatment and control groups. A lack of balance would have alerted us to a potential off-support inference and bias. As t-tests may be influenced by sample size, we used instead the standardized difference to determine whether balance is reached (Pan & Bai, 2015). This is done by simply calculating the standardized difference between treatment and controls based on means and standard deviations (Oakes & Johnson, 2006). However, there is no agreement from previous researchers (based on a review of the literature) on what threshold determines whether balance is achieved; we found in the literature values for this threshold of between 10% and 25% (Holmes, 2014; Pan & Bai, 2015). A lack of balance requires the addition of new covariates to the propensity score model and thus a re-estimation to include these extra covariates. Once balance is achieved, the propensity scores are used as weights in a difference-in-differences regression model (Hirano et al., 2000).

### 4.4 Statistical analysis

We describe below the propensity-score weighted difference-in-differences analysis we used to estimate the effects of the BRT on the outcomes for Bogotá and Quito. For Bogotá, the built-up area model uses the natural logarithm of the built area in each parcel and coefficients are estimated using ordinary least squares regression.

$$ln(y_i) = \beta_0 + \vec{\beta}_{distBRTS}\overrightarrow{DistBRTS_i} + \sum_i^{12} \beta_j * X_{ij} + \vec{\beta}_{landuses}\overrightarrow{LandUses_i} + \vec{\beta}_{strata}\overrightarrow{Strata_i} + \sum_i^{14} \alpha_i * year_i + \sum_i^{14} \lambda_i * year_i * T * Corridor + \varepsilon_i \tag{1}$$

Where $ln(y_i) = logarithm\ of\ built-up\ area\ of\ parcel\ i$

$\beta_0, = intercept$

$\beta_{distBRTS} = is\ a\ vector\ of\ estimated\ coefficients$

$\overrightarrow{DistBRTS_i} = is\ a\ vector\ of\ six\ dummy\ variables\ (one\ excluded\ as\ reference)$
$for\ ranges\ of\ distances\ to\ the\ closest\ BRT\ station\ to\ parcel\ i$

$\beta_j = estimated\ coefficients\ associated\ with\ independent\ variables\ X_j\ of\ parcel\ i$

$X_{ij} = j\ independent\ variables\ of parcel\ i$

$\beta_{landuses} = is\ a\ vector\ of\ estimated\ coefficient$

$\overrightarrow{LandUses_i} = is\ a\ vector\ of\ five\ dummy\ variables, land\ uses\ of\ parcel\ i$

$\beta_{strata} = is\ a\ vector\ of\ estimated\ coefficient$

$\overrightarrow{Strata_i} = is\ a\ vector\ of\ five\ dummy\ variables\ (one\ as\ reference), socioeconomic\ stratum\ of\ parcel\ i$

$\alpha_i = estimated\ coefficient\ for\ effect\ of\ year\ i$

$year_i = dummy\ variable\ for\ years\ 2000\ to\ 2013$

$\lambda_i = estimated\ coefficient\ of\ treatment\ effect\ for\ year\ i\ for\ each\ corridor$

$year_i = dummy\ variables\ for\ year\ i, from\ 2000\ to\ 2013$

$T = dummy\ variable\ \ for\ treatment = 1\ and\ control = 0$

We constructed our regression model for land uses using the same structure as for the built-up area model. One model was estimated for commercial land use (1=yes, 0=no); a second model was estimated for residential land use (1=yes, 0=no). Coefficients for these models were estimated using logistic regression. For Quito, the model for built up areas is shown below.

$$ln(y_i) = \beta_0 + \vec{\beta}_{distBRTS}\overrightarrow{DistBRTS_i} + \sum_{j}^{8} \beta_j * X_{ij} + \vec{\beta}_{AgeConst}\overrightarrow{AgeConst_i} + \vec{\beta}_{landuses}\overrightarrow{Landuses_i} + \sum_{i}^{10} \alpha_i * year_i + \sum_{i}^{10} \lambda_i * year_i * T * corridor + \varepsilon_i \tag{2}$$

Where $ln(y_i) = logarithm\ of\ built - up\ area\ of\ parcel\ i$

$\beta_0 = intercept$

$\beta_{distBRTS} = estimated\ coefficient$

$\overrightarrow{DistBRTS_i} = is\ a\ vector\ of\ six\ dummy\ variables\ (one\ excluded\ as\ reference)$
$for\ ranges\ of\ distances\ to\ the\ closest\ BRT\ station\ to\ parcel\ i$

$\beta_j = estimated\ coefficients\ associated\ with\ independent\ variables\ of\ parcel\ i$

$X_{ij} = vector\ of\ independent\ variables\ ofparcel\ i$

$\beta_{AgeConst} = estimated\ coefficient$

$\overrightarrow{AgeConst_i} = is\ a\ vector\ of\ six\ dummy\ variables, age\ of\ construction\ of\ parcel\ i$

$\beta_{landuses} = estimated\ coefficient$

$\overrightarrow{Landuses_i} = is\ a\ vector\ of\ five\ dummy\ variables, land\ uses\ of\ parcel\ i$

$\alpha_i = estimated\ coefficient\ for\ effect\ of\ year\ i$

$year_i = dummy\ variable\ for\ years\ 2001\ to\ 2010$

$\lambda_i = estimated\ coefficient\ of\ treatment\ effect\ for\ year\ i\ \ for\ each\ corridor$

$year_i = dummy\ variables\ for\ year\ i, from\ 2001\ to\ 2010$

$T = dummy\ variable\ \ for\ treatment = 1\ and\ control = 0$

The model for the redevelopment changes in Quito was estimated using the same structure as the built-up area model but with redevelopment (yes/no) as the outcome variable and was estimated using logistic regression.

For all models, the coefficients denoted by $\lambda$ summarize the effect of treatment by post-year in relation to the control area and the pre-treatment years for each corridor. We modeled the corridors independently due to the potential heterogeneity across corridors that could have influenced our results, thus the interpretation of these models' coefficients depends on the specific regression model being estimated. The dependent variable of the built-up area model is given in the natural logarithm, which we used to estimate the percent change in built-up areas for parcels in the intervention area after BRT investment in relation to the control area and to the before period. For the land use and redevelopment models, the coefficients represent the change in the log odds of the given land use for parcels in the intervention area after BRT investment, in relation to the control area and to the before period.

## 5 Results

### 5.1 Bogotá

An examination of the Bogotá data reveals 56,892 parcels in the treatment group and 41,284 parcels in the control group (Table 2; also shown in Figure 2, treatment in red and control in blue). Regarding land uses, the control parcels tend slightly more towards residential use than the treatment parcels do. Population densities and block sizes are similar between parcels in the treatment group and the control group. Unsurprisingly, the distance to the actual or a future BRT corridor is very similar in both treatment and control land parcels.

**Table 2**. Descriptive statistics years 2000 and 2013 (weighted with propensity scores), Bogotá

| | **Year 2000** | | | | | | | | **Year 2013** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Treatment (N=56,892)** | | | | **Control (N=41,284)** | | | | **Treatment (N=56,892)** | | | | **Control (N=41,284)** | | | |
| **Variable** | **Mean** | **Std. Dev.** | **Min** | **Max** | **Mean** | **Std. Dev.** | **Min** | **Max** | **Mean** | **Std. Dev.** | **Min** | **Max** | **Mean** | **Std. Dev.** | **Min** | **Max** |
| *Dependent variables* | | | | | | | | | | | | | | | | |
| **Ln Built-up Area** | 5.114 | 1.733 | -4.61 | 11.37 | 5.041 | 1.785 | -4.61 | 11.43 | 5.210 | 1.880 | -4.61 | 11.61 | 5.303 | 1.484 | -4.61 | 12.13 |
| **Land Use Residential** | 0.787 | 0.410 | 0.00 | 1.00 | 0.797 | 0.402 | 0.00 | 1.00 | 0.686 | 0.464 | 0.00 | 1.00 | 0.749 | 0.434 | 0.00 | 1.00 |
| **Land Use Commercial** | 0.043 | 0.202 | 0.00 | 1.00 | 0.053 | 0.224 | 0.00 | 1.00 | 0.275 | 0.447 | 0.00 | 1.00 | 0.227 | 0.419 | 0.00 | 1.00 |
| *Independent variables* | | | | | | | | | | | | | | | | |
| **Distance BRT Station** | | | | | | | | | | | | | | | | |
| *≤100 m* | 0.025 | 0.156 | 0.00 | 1.00 | 0.025 | 0.155 | 0.00 | 1.00 | 0.025 | 0.156 | 0.00 | 1.00 | 0.025 | 0.155 | 0.00 | 1.00 |
| *>100m ≤200 m* | 0.114 | 0.318 | 0.00 | 1.00 | 0.115 | 0.319 | 0.00 | 1.00 | 0.114 | 0.318 | 0.00 | 1.00 | 0.115 | 0.319 | 0.00 | 1.00 |
| *>200m ≤300 m* | 0.201 | 0.401 | 0.00 | 1.00 | 0.208 | 0.406 | 0.00 | 1.00 | 0.201 | 0.401 | 0.00 | 1.00 | 0.208 | 0.406 | 0.00 | 1.00 |
| *>300m ≤400 m* | 0.252 | 0.434 | 0.00 | 1.00 | 0.245 | 0.430 | 0.00 | 1.00 | 0.252 | 0.434 | 0.00 | 1.00 | 0.245 | 0.430 | 0.00 | 1.00 |
| *>400 m ≤500 m* | 0.261 | 0.439 | 0.00 | 1.00 | 0.255 | 0.436 | 0.00 | 1.00 | 0.261 | 0.439 | 0.00 | 1.00 | 0.255 | 0.436 | 0.00 | 1.00 |
| *>500 m* | 0.147 | 0.354 | 0.00 | 1.00 | 0.153 | 0.360 | 0.00 | 1.00 | 0.147 | 0.354 | 0.00 | 1.00 | 0.153 | 0.360 | 0.00 | 1.00 |
| **Ln Distance CBD** | 8.849 | 0.553 | 4.32 | 9.67 | 8.929 | 0.118 | 8.52 | 9.35 | 8.849 | 0.553 | 4.32 | 9.67 | 8.929 | 0.118 | 8.52 | 9.35 |
| **Ln Distance corridor** | 5.464 | 0.687 | 2.36 | 6.21 | 5.421 | 0.661 | 2.87 | 6.21 | 5.464 | 0.687 | 2.36 | 6.21 | 5.421 | 0.661 | 2.87 | 6.21 |
| **Land Uses** | | | | | | | | | | | | | | | | |
| *Residential* | 0.787 | 0.410 | 0.00 | 1.00 | 0.797 | 0.402 | 0.00 | 1.00 | 0.686 | 0.464 | 0.00 | 1.00 | 0.749 | 0.434 | 0.00 | 1.00 |
| *Industrial* | 0.153 | 0.360 | 0.00 | 1.00 | 0.131 | 0.337 | 0.00 | 1.00 | 0.003 | 0.053 | 0.00 | 1.00 | 0.009 | 0.096 | 0.00 | 1.00 |
| *Commercial* | 0.043 | 0.202 | 0.00 | 1.00 | 0.053 | 0.224 | 0.00 | 1.00 | 0.275 | 0.447 | 0.00 | 1.00 | 0.227 | 0.419 | 0.00 | 1.00 |
| *Facilities* | 0.025 | 0.157 | 0.00 | 1.00 | 0.022 | 0.146 | 0.00 | 1.00 | 0.024 | 0.153 | 0.00 | 1.00 | 0.014 | 0.119 | 0.00 | 1.00 |
| *Vacant* | 0.008 | 0.088 | 0.00 | 1.00 | 0.011 | 0.104 | 0.00 | 1.00 | 0.008 | 0.091 | 0.00 | 1.00 | 0.007 | 0.082 | 0.00 | 1.00 |
| *Other* | 0.024 | 0.152 | 0.00 | 1.00 | 0.022 | 0.146 | 0.00 | 1.00 | 0.023 | 0.150 | 0.00 | 1.00 | 0.011 | 0.105 | 0.00 | 1.00 |
| *Mixed-use* | 0.036 | 0.187 | 0.00 | 1.00 | 0.031 | 0.174 | 0.00 | 1.00 | 0.019 | 0.136 | 0.00 | 1.00 | 0.017 | 0.131 | 0.00 | 1.00 |
| **Ln Parcel Area** | 5.034 | 0.936 | -4.61 | 13.21 | 5.019 | 0.837 | -4.61 | 13.14 | 5.039 | 0.936 | -4.61 | 13.21 | 5.021 | 0.838 | -4.61 | 13.14 |
| **Ln Properties** | 0.265 | 0.741 | 0.00 | 9.52 | 0.264 | 0.829 | 0.00 | 8.05 | 0.254 | 0.737 | 0.00 | 9.52 | 0.252 | 0.827 | 0.00 | 8.05 |
| **Socioeconomic Level** | | | | | | | | | | | | | | | | |
| *One* | 0.009 | 0.093 | 0.00 | 1.00 | 0.011 | 0.106 | 0.00 | 1.00 | 0.010 | 0.099 | 0.00 | 1.00 | 0.011 | 0.106 | 0.00 | 1.00 |
| *Two* | 0.189 | 0.392 | 0.00 | 1.00 | 0.175 | 0.380 | 0.00 | 1.00 | 0.191 | 0.393 | 0.00 | 1.00 | 0.171 | 0.377 | 0.00 | 1.00 |
| *Three* | 0.619 | 0.486 | 0.00 | 1.00 | 0.630 | 0.483 | 0.00 | 1.00 | 0.631 | 0.483 | 0.00 | 1.00 | 0.642 | 0.479 | 0.00 | 1.00 |
| *Four* | 0.111 | 0.314 | 0.00 | 1.00 | 0.108 | 0.310 | 0.00 | 1.00 | 0.099 | 0.299 | 0.00 | 1.00 | 0.105 | 0.307 | 0.00 | 1.00 |

| | Year 2000 | | | | | | | | Year 2013 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Treatment (N=56,892) | | | | Control (N=41,284) | | | | Treatment (N=56,892) | | | | Control (N=41,284) | | | |
| **Variable** | **Mean** | **Std. Dev.** | **Min** | **Max** | **Mean** | **Std. Dev.** | **Min** | **Max** | **Mean** | **Std. Dev.** | **Min** | **Max** | **Mean** | **Std. Dev.** | **Min** | **Max** |
| *Five* | 0.048 | 0.214 | 0.00 | 1.00 | 0.054 | 0.226 | 0.00 | 1.00 | 0.050 | 0.217 | 0.00 | 1.00 | 0.048 | 0.213 | 0.00 | 1.00 |
| *Six* | 0.023 | 0.151 | 0.00 | 1.00 | 0.023 | 0.149 | 0.00 | 1.00 | 0.020 | 0.139 | 0.00 | 1.00 | 0.022 | 0.147 | 0.00 | 1.00 |
| **Ln Property Value** | 4.069 | 0.929 | -2.03 | 10.56 | 4.052 | 0.733 | 0.18 | 10.74 | 5.336 | 1.000 | -1.90 | 12.61 | 5.404 | 0.715 | 2.11 | 13.94 |
| **Ln Population Density** | 5.383 | 0.595 | -4.27 | 6.31 | 5.409 | 0.770 | -1.06 | 6.18 | 5.743 | 1.418 | -7.06 | 16.67 | 5.684 | 1.810 | -8.41 | 16.83 |
| **Ln Block Size** | 8.385 | 0.811 | -3.87 | 13.36 | 8.388 | 0.771 | -1.93 | 13.32 | 8.386 | 0.831 | -2.04 | 12.74 | 8.385 | 0.778 | -1.93 | 13.01 |
| **Ln Roads Ratio** | -0.367 | 0.087 | -0.76 | -0.01 | -0.363 | 0.070 | -0.57 | -0.01 | -0.367 | 0.087 | -0.76 | -0.01 | -0.363 | 0.070 | -0.57 | -0.01 |
| **Ln Parks Ratio** | -3.616 | 1.813 | -9.21 | -0.08 | -3.512 | 1.789 | -9.21 | -1.35 | -3.616 | 1.813 | -9.21 | -0.08 | -3.512 | 1.789 | -9.21 | -1.35 |
| **Ln Facilities Density** | -1.420 | 0.753 | -4.61 | 0.06 | -1.442 | 0.568 | -4.61 | -0.41 | -1.420 | 0.753 | -4.61 | 0.06 | -1.442 | 0.568 | -4.61 | -0.41 |
| **Completed sqmt Ratio** | 0.095 | 0.119 | 0.00 | 0.79 | 0.095 | 0.152 | 0.00 | 1.00 | 0.165 | 0.152 | 0.00 | 1.00 | 0.184 | 0.162 | 0.00 | 0.92 |
| **New sqmt Ratio** | 0.145 | 0.183 | 0.00 | 1.00 | 0.149 | 0.153 | 0.00 | 1.00 | 0.176 | 0.159 | 0.00 | 1.00 | 0.210 | 0.191 | 0.00 | 1.00 |
| **Progress sqmt Ratio** | 0.443 | 0.348 | 0.00 | 1.00 | 0.439 | 0.312 | 0.00 | 1.00 | 0.441 | 0.274 | 0.00 | 1.00 | 0.452 | 0.238 | 0.00 | 0.94 |

### 5.1.1 Propensity scores of parcels falling within the treatment area

Although we constructed propensity scores to adequately specify the BRT effect, the results we obtained from our propensity score equation also provide insights regarding the relationship between the covariates and the treatment condition (whether BRT is operating within a corridor). The equation results suggest that parcels closer to the city center are more likely to be in the treatment group, i.e., they are more likely receive treatment, which means access to BRT (Supplementary Table A2). With respect to land-use type, the results suggest that parcels with industrial and commercial land uses are more likely to have BRT service than are the residential land-use parcels (reference category). However, this is not the case for vacant, other land uses, and vertical mixed uses.

The parcel area variable suggests large parcels are less likely to have BRT service, but that parcels with lower appraised values are more likely to have such service. This in turn suggests that the implementation of BRT systems is more likely to occur in those areas with lower property values, possibly due to the noise and concentration of activities along main arterial roads (e.g., those where trunk corridors can be implemented) as well as to right of way decisions intended to minimize land acquisition costs. Neighborhood-level variables show that the parcels in neighborhoods with higher road ratios and a higher density of public facilities are more likely to receive treatment (access to the BRT).

On the other hand, a greater prevalence of parks (park ratio) was associated with a lower likelihood of being in the treatment area. The coefficient for the density of facilities variable suggests that the high concentration of primary destinations within a single neighborhood increases its probability of being served by mass transit, which makes sense considering that these types of transportation investment seek to connect to such destinations within the city.

### 5.1.2 Impact of BRT on built-up areas

All variables described previously (except property value, excluded due to possible endogeneity) were included in the regression model as covariates (Table 3). The outcomes of the variables capturing interactions with the treatment effect show little variation in built up areas for parcels along "*Av Caracas*" in relation to the control area. The results are cumulative (Figure 3), which means that for *Av Caracas t*he total change between 2001 and 2003 was 18.86% (the sum of 2001's increment of 6.95%, 2002's increment of 4.94%, and 2003's increament of 6.96%). Our equation results also suggest a significant decrease for parcels served by "*Av. Autonorte*" until 2005 (-1.10%), but in 2006 there was an increment of 4.72%, which served as the start of a positive trend until 2013 (Figure 3). Although there is a lower percentage of built area along "*Av Calle 80*" than in control corridors and other intervention corridors, the difference decreases after 2002.

**Table 3.** Propensity score weighted regression results, Bogotá

| | **Model 1**<br>**Dependent variable: ln(built-up area)** | | | **Model 2**<br>**Dependent variable: Residential Land Use** | | | **Model 3**<br>**Dependent variable: Commercial Land Use** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Estimated coefficients†** | | **Standard errors** | **Estimated coefficients†** | | **Standard errors** | **Estimated coefficients†** | | **Standard errors** |
| **Distance BRT Station** | | | | | | | | | |
| ≤100 m | (reference) | | | (reference) | | | | | |
| *>100m ≤200 m* | 0.017 | * | 0.007 | 0.449 | *** | 0.017 | -0.497 | *** | 0.018 |
| *>200m ≤300 m* | 0.010 | | 0.007 | 0.520 | *** | 0.017 | -0.628 | *** | 0.018 |
| *>300m ≤400 m* | 0.024 | ** | 0.007 | 0.510 | *** | 0.018 | -0.647 | *** | 0.019 |
| *>400 m ≤500 m* | 0.023 | * | 0.008 | 0.445 | *** | 0.020 | -0.609 | *** | 0.021 |
| *>500 m* | -0.082 | *** | 0.008 | 0.154 | *** | 0.021 | -0.392 | *** | 0.022 |
| **Ln Distance CBD** | -0.077 | *** | 0.003 | 0.740 | *** | 0.009 | -0.819 | *** | 0.009 |
| **Ln Distance BRT corridor** | -0.025 | *** | 0.002 | 0.450 | *** | 0.007 | -0.424 | *** | 0.007 |
| **Land Uses** | | | | | | | | | |
| *Vacant* | (reference) | | | | | | | | |
| *Residential* | 0.299 | *** | 0.009 | | | | | | |
| *Industrial* | 0.104 | *** | 0.004 | | | | | | |
| *Commercial* | -1.050 | *** | 0.069 | | | | | | |
| *Facilities* | -9.161 | *** | 0.029 | | | | | | |
| *Other* | -10.304 | *** | 0.024 | | | | | | |
| *Mixed-use* | -0.102 | *** | 0.016 | | | | | | |
| **Ln Parcel Area** | 0.671 | *** | 0.004 | -0.970 | *** | 0.010 | 0.295 | *** | 0.009 |
| **Ln Properties** | 0.310 | *** | 0.002 | 0.612 | *** | 0.010 | 0.193 | *** | 0.008 |
| **Socioeconomic level** | | | | | | | | | |
| *Six* | (reference) | | | | | | | | |
| *Five* | -0.037 | *** | 0.009 | -0.044 | | 0.036 | 0.004 | | 0.232 |
| *Four* | -0.104 | *** | 0.009 | 0.092 | * | 0.033 | -0.342 | *** | 0.041 |
| *Three* | 0.024 | * | 0.011 | -1.034 | *** | 0.033 | 0.461 | *** | 0.033 |
| *Two* | 0.030 | * | 0.013 | -0.781 | *** | 0.039 | -0.038 | *** | 0.032 |
| *One* | -0.326 | *** | 0.032 | -1.927 | *** | 0.106 | -0.005 | *** | 0.032 |
| **Ln Population Density** | 0.014 | *** | 0.003 | 0.489 | *** | 0.007 | -0.131 | *** | 0.008 |
| **Ln Block Size** | 0.001 | | 0.002 | -0.124 | *** | 0.007 | 0.135 | *** | 0.006 |
| **Ln Roads Ratio** | -0.206 | *** | 0.036 | 0.370 | *** | 0.067 | -0.931 | *** | 0.063 |
| **Ln Parks Ratio** | -0.009 | *** | 0.001 | 0.131 | *** | 0.002 | -0.149 | *** | 0.002 |
| **Ln Facilities Density** | 0.072 | *** | 0.008 | -0.095 | *** | 0.017 | 0.230 | *** | 0.015 |
| **Built-up area in m2** | -0.042 | *** | 0.008 | -0.172 | *** | 0.020 | 0.300 | *** | 0.026 |

| | Model 1<br>Dependent variable: ln(built-up area) | | | Model 2<br>Dependent variable: Residential Land Use | | | Model 3<br>Dependent variable: Commercial Land Use | | |
|---|---|---|---|---|---|---|---|---|---|
| | Estimated coefficients† | | Standard errors | Estimated coefficients† | | Standard errors | Estimated coefficients† | | Standard errors |
| **New built-up area in m2** | -0.038 | ** | 0.014 | 0.012 | | 0.022 | 0.157 | *** | 0.024 |
| **Square meters under const.** | -0.029 | *** | 0.006 | -0.220 | *** | 0.014 | 0.358 | *** | 0.016 |
| **Year** | | | | | | | | | |
| *Year 2001* | 0.102 | *** | 0.011 | -0.039 | | 0.026 | 0.854 | *** | 0.054 |
| *Year 2002* | 0.174 | *** | 0.010 | 0.067 | * | 0.027 | 1.140 | *** | 0.053 |
| *Year 2003* | 0.195 | *** | 0.010 | -0.017 | | 0.027 | 1.348 | *** | 0.054 |
| *Year 2004* | 0.215 | *** | 0.009 | -0.029 | | 0.027 | 1.373 | *** | 0.054 |
| *Year 2005* | 0.215 | *** | 0.009 | -0.052 | * | 0.027 | 1.377 | *** | 0.054 |
| *Year 2006* | 0.253 | *** | 0.010 | -0.094 | *** | 0.026 | 1.365 | *** | 0.054 |
| *Year 2007* | 0.252 | *** | 0.010 | -0.116 | *** | 0.026 | 1.368 | *** | 0.054 |
| *Year 2008* | 0.252 | *** | 0.010 | -0.130 | *** | 0.027 | 1.369 | *** | 0.054 |
| *Year 2009* | 0.277 | *** | 0.009 | -0.157 | *** | 0.025 | 1.435 | *** | 0.054 |
| *Year 2010* | 0.284 | *** | 0.009 | -0.360 | *** | 0.025 | 1.667 | *** | 0.052 |
| *Year 2011* | 0.295 | *** | 0.009 | -0.436 | *** | 0.024 | 1.762 | *** | 0.050 |
| *Year 2012* | 0.302 | *** | 0.009 | -0.446 | *** | 0.024 | 1.776 | *** | 0.050 |
| *Year 2013* | 0.318 | *** | 0.010 | -0.437 | *** | 0.024 | 1.754 | *** | 0.050 |
| **Average Treatment Effect** | | | | 0.041 | | 0.025 | | | |
| *T* Year 2000*Caracas* | 0.114 | *** | 0.011 | 0.033 | | 0.024 | -0.962 | *** | 0.054 |
| *T* Year 2001*Caracas* | 0.067 | *** | 0.009 | 0.046 | | 0.025 | -0.196 | *** | 0.034 |
| *T* Year 2002*Caracas* | 0.048 | *** | 0.008 | 0.020 | | 0.025 | -0.114 | *** | 0.031 |
| *T* Year 2003*Caracas* | 0.067 | *** | 0.007 | 0.031 | | 0.025 | 0.007 | | 0.033 |
| *T* Year 2004*Caracas* | 0.059 | *** | 0.006 | 0.042 | | 0.025 | -0.019 | | 0.033 |
| *T* Year 2005*Caracas* | 0.057 | *** | 0.006 | 0.083 | * | 0.025 | -0.025 | | 0.033 |
| *T* Year 2006*Caracas* | 0.075 | *** | 0.007 | 0.072 | ** | 0.025 | -0.079 | * | 0.033 |
| *T* Year 2007*Caracas* | 0.076 | *** | 0.007 | 0.053 | ** | 0.025 | -0.072 | * | 0.033 |
| *T* Year 2008*Caracas* | 0.075 | *** | 0.007 | -0.147 | * | 0.023 | -0.054 | | 0.033 |
| *T* Year 2009*Caracas* | 0.075 | *** | 0.006 | -0.087 | *** | 0.022 | 0.061 | | 0.032 |
| *T* Year 2010*Caracas* | 0.066 | *** | 0.006 | -0.078 | *** | 0.022 | -0.052 | | 0.029 |
| *T* Year 2011*Caracas* | 0.068 | *** | 0.006 | -0.088 | *** | 0.022 | -0.085 | ** | 0.026 |
| *T* Year 2012*Caracas* | 0.070 | *** | 0.006 | -0.077 | *** | 0.022 | -0.079 | * | 0.026 |
| *T* Year 2013*Caracas* | 0.070 | *** | 0.006 | 0.041 | *** | 0.025 | -0.103 | *** | 0.026 |
| *T* Year 2000*Autonorte* | 0.086 | *** | 0.015 | 0.114 | * | 0.039 | 0.600 | *** | 0.065 |
| *T* Year 2001*Autonorte* | 0.062 | *** | 0.013 | -0.109 | * | 0.037 | 0.696 | *** | 0.045 |
| *T* Year 2002*Autonorte* | 0.013 | | 0.014 | -0.224 | *** | 0.038 | 0.433 | *** | 0.043 |

| | Model 1<br>Dependent variable: ln(built-up area) | | | Model 2<br>Dependent variable: Residential Land Use | | | Model 3<br>Dependent variable: Commercial Land Use | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Estimated coefficients†** | | **Standard errors** | **Estimated coefficients†** | | **Standard errors** | **Estimated coefficients†** | | **Standard errors** |
| *T* Year 2003*Autonorte* | -0.003 | | 0.013 | -0.262 | *** | 0.037 | 0.435 | *** | 0.043 |
| *T* Year 2004*Autonorte* | -0.011 | | 0.012 | -0.421 | *** | 0.036 | 0.610 | *** | 0.043 |
| *T* Year 2005*Autonorte* | -0.011 | | 0.012 | -0.421 | *** | 0.036 | 0.621 | *** | 0.043 |
| *T* Year 2006*Autonorte* | 0.046 | ** | 0.015 | -0.422 | *** | 0.036 | 0.590 | *** | 0.043 |
| *T* Year 2007*Autonorte* | 0.043 | ** | 0.014 | -0.424 | *** | 0.036 | 0.591 | *** | 0.043 |
| *T* Year 2008*Autonorte* | 0.066 | *** | 0.014 | -0.532 | *** | 0.035 | 0.695 | *** | 0.042 |
| *T* Year 2009*Autonorte* | 0.048 | ** | 0.014 | -0.495 | *** | 0.037 | 0.736 | *** | 0.042 |
| *T* Year 2010*Autonorte* | 0.018 | | 0.013 | -0.543 | *** | 0.036 | 0.926 | *** | 0.039 |
| *T* Year 2011*Autonorte* | 0.019 | | 0.012 | -0.570 | *** | 0.035 | 0.931 | *** | 0.036 |
| *T* Year 2012*Autonorte* | 0.014 | | 0.013 | -0.584 | *** | 0.035 | 0.932 | *** | 0.036 |
| *T* Year 2013*Autonorte* | 0.019 | | 0.013 | -0.571 | *** | 0.035 | 0.919 | *** | 0.037 |
| *T* Year 2000*Calle 80* | -0.205 | ** | 0.079 | 0.438 | *** | 0.084 | -1.655 | *** | 0.093 |
| *T* Year 2001*Calle 80* | -0.180 | * | 0.079 | 0.327 | *** | 0.073 | -0.026 | | 0.095 |
| *T* Year 2002*Calle 80* | -0.063 | * | 0.010 | 0.269 | *** | 0.076 | -0.051 | | 0.080 |
| *T* Year 2003*Calle 80* | -0.086 | *** | 0.010 | 0.364 | *** | 0.076 | -0.272 | ** | 0.081 |
| *T* Year 2004*Calle 80* | -0.086 | *** | 0.009 | 0.341 | *** | 0.075 | -0.427 | *** | 0.071 |
| *T* Year 2005*Calle 80* | -0.086 | *** | 0.009 | 0.352 | *** | 0.076 | -0.458 | *** | 0.070 |
| *T* Year 2006*Calle 80* | -0.104 | *** | 0.009 | 0.289 | *** | 0.073 | -0.402 | *** | 0.069 |
| *T* Year 2007*Calle 80* | -0.103 | *** | 0.009 | 0.296 | *** | 0.073 | -0.418 | *** | 0.069 |
| *T* Year 2008*Calle 80* | -0.107 | *** | 0.009 | 0.293 | *** | 0.073 | -0.409 | *** | 0.069 |
| *T* Year 2009*Calle 80* | -0.134 | *** | 0.009 | 0.325 | *** | 0.074 | -0.477 | *** | 0.069 |
| *T* Year 2010*Calle 80* | -0.107 | *** | 0.009 | 0.225 | *** | 0.063 | -0.400 | *** | 0.057 |
| *T* Year 2011*Calle 80* | -0.108 | *** | 0.009 | 0.222 | *** | 0.061 | -0.421 | *** | 0.054 |
| *T* Year 2012*Calle 80* | -0.106 | *** | 0.009 | 0.217 | *** | 0.060 | -0.420 | *** | 0.054 |
| *T* Year 2013*Calle 80* | -0.106 | *** | 0.009 | 0.208 | ** | 0.060 | -0.416 | *** | 0.054 |
| **Constant term** | 2.433 | *** | 0.067 | -3.425 | *** | 0.154 | 4.111 | *** | 0.143 |
| | | | | | | | | | |
| N | 1,374,464 | | N | 1,374,464 | | | 1,374,464 | | |
| F (83,1374380) | 11747.89 | | Log pseudo likelihood | -1204126.1 | | | | | |
| Prob > F | 0.0000 | | Wald chi2(77) | 86082.71 | | | 87501.49 | | |
| R-squared | 0.8091 | | Prob > chi2 | 0.000 | | | 0.000 | | |
| Root MSE | 0.7372 | | Pseudo R2 | 0.1937 | | | 0.1333 | | |
| ††F statistic: (2,1374380) | | | | | | | | | |

* p<0.05, ** p<0.01, *** p<0.001

**Figure 3.** Estimated average effect of BRT on built-up area change (percentages) over time by BRT corridor, Bogotá, Colombia

Note: 95% confidence intervals not shown for parsimony. Not all coefficients are statistically significant. Refer to Table 3 for statistical significance of estimated coefficients. Polynomial spline shown to describe trend.
Percentages estimated based on the coefficient results shown in Table 3.

### 5.1.3 Impact of BRT on residential and commercial land uses

For the model of residential uses, our results (Table 3) for the interaction variables of the treatment effect suggest a consistent decrease in the probability of the establishment of residential land uses, although with differences across corridors. Parcels served by the BRT along "*Av Caracas*" experienced decreases in the probability of being put to residential use after 2006 with the only exception of year 2009, we found that between 2006 (79.56%) and 2008 (79.61%), with a slight increase in 2009 (80.01%).

Our findings suggest slight changes in a mostly urban consolidated area that was subject to infill developments until 2008, after which the probability of residential land use decreased over time in relation to the control parcels. Parcels located along "*Av Autonorte"* experienced significant changes in the probability of being categorized as residential land use over time, with a decreasing trend after the opening of the BRT's commercial operations in 2001 (74.11%) until 2013 (66.72%). These findings suggest a rapid dynamic with significant changes along the corridor, mostly with a decline in residential land use in relation to the control parcels over time. However, parcels located along "*Av Calle 80*" experienced minor decreases in residential land use that became more prominent midway through the study period, i.e., after 2009 (80.01%; Figure 4). Our findings for "*Av Calle 80*" suggest that there was an important dynamic in residential development until 2009, after which the probability of the establishment of residential land use decreased over time, but was still larger than that of the controls.

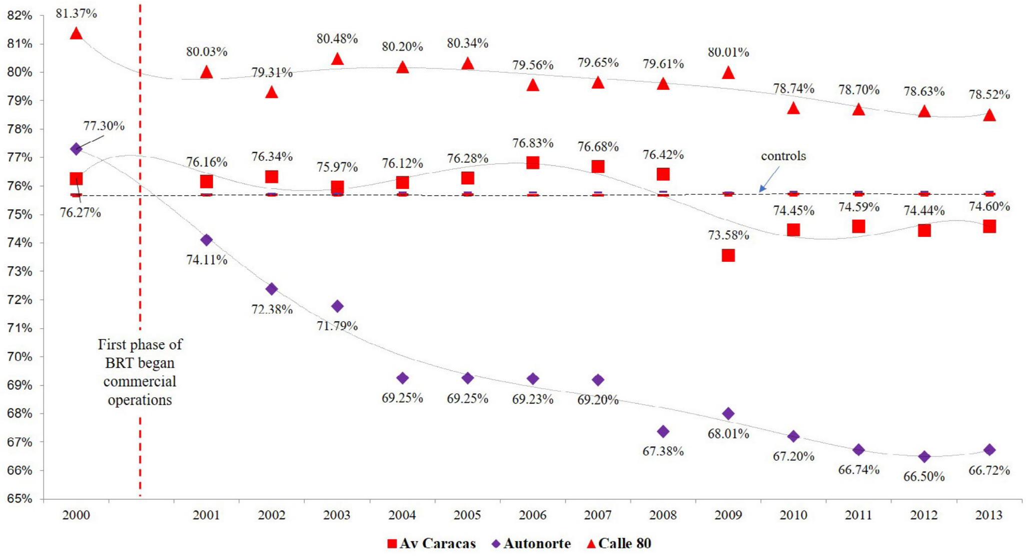


**Figure 4.** Average predicted probability of residential land use over time per BRT corridor, Bogotá, Colombia

Note: 95% confidence intervals not shown for parsimony. Not all coefficients are statistically significant. Refer to Table 3 for statistical significance of estimated coefficients. Polynomial spline shown to describe trend.

The results we obtained using the distance to the BRT station (or future station for the control parcels) suggest residential land-use changes are more likely to occur more than 100 meters away from the BRT station (current or future). This finding is consistent with the land value increase curve identified by Rodriguez and Targa (2004) in which parcels facing the trunk corridor have a lower curve than those further away (more than 100 meters). Our results for the distance to the CBD and for the distance to the corridor or main arterial road suggest residential land uses are more likely to occur further away from the city center as well as from main arterial roads. The variables for parcel area and properties (number of residential units within a parcel) suggest that residential land use is more likely to occur in small parcels with a greater land use intensity (a larger number of properties within the parcel).

However, the results for commercial land uses (Table 3) suggest a probability of increasing this type of land use over time throughout the corridors. All parcels in treatment corridors were subject to a early steep increase, which then stabilized, after which it increased again later in the study period (Figure 5). Despite the increase between 2000 and 2001 in the "*Av Caracas*" corridor, the larger probability in relation to controls only occurred in 2009. However, the effect of the BRT Corridor "*Autonorte*" shows the largest probabilities in relation to the control areas and also shows an increasing trend, especially between 2004 (28.50%) and 2013 (33.99%). Not only does this corridor present larger probabilities than the controls over time, but it demonstrates an increasing pattern since 2006, mostly due to the new developments that took place along the corridor for commercial and office buildings. The effect for BRT Corridor "*Av Calle 80*" suggests a lower prevalence of commercial land use in relation to the control parcels, especially after 2001 (18.91%). These results suggest that the commercial land-use type experienced an increase in its probability between 2000 and 2001 within the corridor, but also that this was less than the estimated probabilities for the control parcels over time.

**Figure 5.** Average predicted probability of commercial land uses over time by BRT corridor, Bogotá, Colombia

Note: 95% confidence intervals not shown for parsimony. Not all coefficients are statistically significant. Refer to Table 3 for statistical significance of estimated coefficients. Polynomial spline shown to describe trend.

Our results for the variable representing the distance to the BRT station (future station for the control parcels) suggest the opposite relationship from that which we observed for residential land uses. Commercial land-use changes are more likely to occur within 100 meters from the transit station. Our results for distance to the CBD and distance to the corridor or main arterial road followed the same pattern. Commercial land uses are more likely to occur near main activity nodes such as the CBD or closer to main arterial roads. The variables representing parcel area and density of properties suggest commercial land uses are more likely to be established in larger parcels, with more properties (residential units within a parcel) within the parcel.

## 5.2 Quito

The data for Quito contain 6,058 parcels in the treatment group and 7,493 parcels in the control group (Table 4). The location factor variables showed a similarity between treatment and control groups in terms of distances to BRT stations (current and future) as well as distances to BRT corridors and arterial roads (controls). Block sizes were also similar between treatment and control parcels. There were slight differences between treatment and control groups in terms of distances to the CBD and population densities, which are related to the city's urban growth with greater consolidation towards the north.

**Table 4.** Descriptive statistics year 2001 and 2010 (weighted with propensity scores), Quito, Ecuador

| | Year 2001 | | | | | | | | Year 2010 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Treatment (N=6,058) | | | | Control (N=7,493) | | | | Treatment (N=6,058) | | | | Control (N=7,493) | | | |
| Variable | Mean | Std. Dev. | Min | Max | Mean | Std. Dev. | Min | Max | Mean | Std. Dev. | Min | Max | Mean | Std. Dev. | Min | Max |
| ***Dependent variables*** | | | | | | | | | | | | | | | | |
| **Ln Built-up area** | 2.855 | 4.578 | -8.46 | 9.09 | 3.196 | 4.161 | -7.84 | 8.62 | 5.210 | 1.866 | -5.25 | 9.09 | 5.174 | 1.554 | -6.25 | 8.96 |
| **New Developments** | 0.035 | 0.184 | 0.00 | 1.00 | 0.019 | 0.136 | 0.00 | 1.00 | 0.005 | 0.068 | 0.00 | 1.00 | 0.013 | 0.112 | 0.00 | 1.00 |
| ***Independent variables*** | | | | | | | | | | | | | | | | |
| **Distance BRT Station** | | | | | | | | | | | | | | | | |
| *≤100 m* | 0.068 | 0.252 | 0.00 | 1.00 | 0.053 | 0.223 | 0.00 | 1.00 | 0.068 | 0.252 | 0.00 | 1.00 | 0.053 | 0.223 | 0.00 | 1.00 |
| *>100m ≤200 m* | 0.165 | 0.371 | 0.00 | 1.00 | 0.149 | 0.356 | 0.00 | 1.00 | 0.165 | 0.371 | 0.00 | 1.00 | 0.149 | 0.356 | 0.00 | 1.00 |
| *>200m ≤300 m* | 0.225 | 0.418 | 0.00 | 1.00 | 0.226 | 0.418 | 0.00 | 1.00 | 0.225 | 0.418 | 0.00 | 1.00 | 0.226 | 0.418 | 0.00 | 1.00 |
| *>300m ≤400 m* | 0.206 | 0.404 | 0.00 | 1.00 | 0.222 | 0.415 | 0.00 | 1.00 | 0.206 | 0.404 | 0.00 | 1.00 | 0.222 | 0.415 | 0.00 | 1.00 |
| *>400 m ≤500 m* | 0.200 | 0.400 | 0.00 | 1.00 | 0.198 | 0.398 | 0.00 | 1.00 | 0.200 | 0.400 | 0.00 | 1.00 | 0.198 | 0.398 | 0.00 | 1.00 |
| *>500 m* | 0.136 | 0.343 | 0.00 | 1.00 | 0.154 | 0.361 | 0.00 | 1.00 | 0.136 | 0.343 | 0.00 | 1.00 | 0.154 | 0.361 | 0.00 | 1.00 |
| **Ln Distance CBD** | 8.382 | 0.507 | 6.90 | 9.21 | 8.410 | 0.391 | 7.26 | 8.97 | 8.382 | 0.507 | 6.90 | 9.21 | 8.410 | 0.391 | 7.26 | 8.97 |
| **Ln Distance corridor** | 5.283 | 0.839 | 2.75 | 6.21 | 5.338 | 0.792 | 2.25 | 6.21 | 5.283 | 0.839 | 2.75 | 6.21 | 5.338 | 0.792 | 2.25 | 6.21 |
| **Ln Parcel Area** | 5.217 | 1.523 | -2.26 | 8.98 | 5.427 | 0.682 | -0.05 | 10.20 | 5.217 | 1.523 | -2.26 | 8.98 | 5.427 | 0.682 | -0.05 | 10.20 |
| **Age of construction** | | | | | | | | | | | | | | | | |
| *2001-2010* | 0.260 | 0.439 | 0.00 | 1.00 | 0.225 | 0.418 | 0.00 | 1.00 | 0.260 | 0.439 | 0.00 | 1.00 | 0.225 | 0.418 | 0.00 | 1.00 |
| *1991-2001* | 0.328 | 0.470 | 0.00 | 1.00 | 0.340 | 0.474 | 0.00 | 1.00 | 0.328 | 0.470 | 0.00 | 1.00 | 0.340 | 0.474 | 0.00 | 1.00 |
| *1981-1991* | 0.211 | 0.408 | 0.00 | 1.00 | 0.220 | 0.414 | 0.00 | 1.00 | 0.211 | 0.408 | 0.00 | 1.00 | 0.220 | 0.414 | 0.00 | 1.00 |
| *1971-1981* | 0.112 | 0.316 | 0.00 | 1.00 | 0.123 | 0.329 | 0.00 | 1.00 | 0.112 | 0.316 | 0.00 | 1.00 | 0.123 | 0.329 | 0.00 | 1.00 |
| *1961-1971* | 0.055 | 0.229 | 0.00 | 1.00 | 0.058 | 0.233 | 0.00 | 1.00 | 0.055 | 0.229 | 0.00 | 1.00 | 0.058 | 0.233 | 0.00 | 1.00 |
| *Before 1961* | 0.033 | 0.179 | 0.00 | 1.00 | 0.034 | 0.181 | 0.00 | 1.00 | 0.033 | 0.179 | 0.00 | 1.00 | 0.034 | 0.181 | 0.00 | 1.00 |
| **Land Uses** | | | | | | | | | | | | | | | | |
| *Residential* | 0.722 | 0.448 | 0.00 | 1.00 | 0.703 | 0.457 | 0.00 | 1.00 | 0.722 | 0.448 | 0.00 | 1.00 | 0.703 | 0.457 | 0.00 | 1.00 |
| *Mixed* | 0.295 | 0.709 | 0.00 | 1.00 | 0.290 | 0.704 | 0.00 | 1.00 | 0.295 | 0.709 | 0.00 | 1.00 | 0.290 | 0.704 | 0.00 | 1.00 |
| *Institutional* | 0.049 | 0.381 | 0.00 | 1.00 | 0.042 | 0.354 | 0.00 | 1.00 | 0.049 | 0.381 | 0.00 | 1.00 | 0.042 | 0.354 | 0.00 | 1.00 |
| *Other* | 0.458 | 1.274 | 0.00 | 1.00 | 0.552 | 1.379 | 0.00 | 1.00 | 0.458 | 1.274 | 0.00 | 1.00 | 0.552 | 1.379 | 0.00 | 1.00 |
| **Ln Population Density** | 3.644 | 2.358 | -4.61 | 6.44 | 3.525 | 3.063 | -4.61 | 8.92 | 4.062 | 1.237 | -4.61 | 5.67 | 5.033 | 0.619 | -4.61 | 6.47 |
| **Ln Block Size** | 9.384 | 1.949 | -4.61 | 11.90 | 9.498 | 1.211 | -4.61 | 13.11 | 9.384 | 1.949 | -4.61 | 11.90 | 9.498 | 1.211 | -4.61 | 13.11 |
| **Ln Roads Ratio** | -0.185 | 0.033 | -0.25 | -0.11 | -0.183 | 0.043 | -0.33 | -0.07 | -0.185 | 0.033 | -0.25 | -0.11 | -0.183 | 0.043 | -0.33 | -0.07 |
| **Ln Parks Ratio** | -3.757 | 1.511 | -9.56 | -0.57 | -3.740 | 1.337 | -6.68 | -0.59 | -3.757 | 1.511 | -9.56 | -0.57 | -3.740 | 1.337 | -6.68 | -0.59 |
| **Ln Facilities Density** | -1.563 | 0.632 | -4.61 | -0.54 | -1.575 | 0.831 | -4.61 | -0.22 | -1.563 | 0.632 | -4.61 | -0.54 | -1.575 | 0.831 | -4.61 | -0.22 |

### 5.2.1. Propensity scores of parcels falling within treatment area

The propensity score model equation suggests that parcels closer to the city center were less likely to be treated, which can be explained by the fact that the Historic Center is classified as heritage (Supplementary Table A3). The result for distance to the BRT corridor is similar to the result for Bogotá. However, a key difference is that large size parcels are more likely to be treated in Quito. In terms of land-use types, mixed-use parcels are more likely to have service than those with only residential use (reference category). The population density is greater in treated areas, confirming the association we observed between the provision of mass transit and the concentration of transportation demand, especially in urban expansion areas in the north and south of the city (Quito, 2012).

### 5.2.2 Impact of BRT on built area

The BRT system's effect suggests a heterogeneity of effects across the two corridors (Table 5). Along the "*Ecovia*" corridor, the new built area increased over time and the growth here was greater than the growth in the built area along "*Corredor Norte.*" Parcels along "*Corredor Norte*" grew the most in terms of built area right before the BRT system opened, a level maintained throughout the study period (Figure 6). As expected, the coefficient for the distance to the CBD and the distance to the BRT are negative, suggesting that the built-up area diminished when moving away from the primary activity nodes or from arterial roads. As we observed in Bogotá, parcel area in Quito is also a strong predictor of a built-up area.

**Table 5.** Propensity score weighted regression analysis results, Quito

| | **Model 1**<br>**Dependent variable: Ln built-up area** | | | **Model 2**<br>**Dependent variable: Redevelopments** | | |
|---|---|---|---|---|---|---|
| | **Estimated coefficients†** | | **Standard errors** | **Estimated coefficients†** | | **Standard errors** |
| **Distance BRT Station** | | | | | | |
| ≤100 m | (reference) | | | | | |
| *>100m ≤200 m* | 0.179 | * | 0.076 | 0.141 | | 0.224 |
| *>200m ≤300 m* | 0.121 | | 0.073 | 0.026 | | 0.219 |
| *>300m ≤400 m* | 0.297 | *** | 0.081 | 0.051 | | 0.242 |
| *>400 m ≤500 m* | 0.228 | ** | 0.088 | -0.055 | | 0.264 |
| *>500 m* | -0.076 | | 0.089 | -0.033 | | 0.269 |
| **Ln Distance CBD** | -0.139 | *** | 0.022 | 0.185 | ** | 0.068 |
| **Ln Distance BRT corridor** | -0.159 | *** | 0.027 | 0.046 | | 0.076 |
| **Ln Parcel Area** | 0.482 | *** | 0.017 | -0.153 | *** | 0.038 |
| **Age of construction** | | | | | | |
| *Before 1961* | (reference) | | | | | |
| *1961-1971* | -4.148 | | 0.049 | | | |
| *1971-1981* | -0.019 | ** | 0.031 | | | |
| *1981-1991* | 0.030 | | 0.031 | | | |
| *1991-2001* | 0.104 | | 0.032 | | | |
| *2001-2010* | 0.014 | *** | 0.034 | | | |
| **Land Uses** | | | | | | |
| *Residential* | (reference) | | | | | |
| *Mixed* | -0.017 | | 0.032 | -0.273 | *** | 0.075 |
| *Institutional* | 0.168 | * | 0.065 | -0.428 | | 0.230 |
| *Other* | 0.146 | ** | 0.049 | -0.113 | | 0.155 |
| **Ln Population Density** | -0.005 | | 0.004 | 0.011 | | 0.013 |
| **Ln Block Size** | 0.016 | ** | 0.005 | -0.008 | | 0.015 |
| **Ln Roads Ratio** | -1.164 | *** | 0.271 | -4.336 | *** | 0.846 |
| **Ln Parks Ratio** | -0.006 | | 0.011 | -0.022 | | 0.034 |
| **Ln Facilities Density** | 0.095 | *** | 0.013 | -0.095 | ** | 0.035 |
| **Year** | | | | | | |
| *Year 2001* | 0.266 | *** | 0.054 | (reference) | | |
| *Year 2002* | 0.492 | *** | 0.054 | 0.404 | ** | 0.132 |
| *Year 2003* | 0.786 | *** | 0.054 | 0.275 | * | 0.130 |
| *Year 2004* | 1.279 | *** | 0.053 | 0.526 | *** | 0.124 |
| *Year 2005* | 1.601 | *** | 0.051 | 1.096 | *** | 0.111 |

| | Model 1<br>Dependent variable: Ln built-up area | | | Model 2<br>Dependent variable: Redevelopments | | |
|---|---|---|---|---|---|---|
| | Estimated coefficients† | | Standard errors | Estimated coefficients† | | Standard errors |
| *Year 2006* | 1.728 | *** | 0.051 | 0.573 | *** | 0.123 |
| *Year 2007* | 1.783 | *** | 0.050 | -0.420 | * | 0.169 |
| *Year 2008* | 1.858 | *** | 0.050 | -1.190 | *** | 0.241 |
| *Year 2009* | 1.986 | *** | 0.049 | -0.960 | *** | 0.224 |
| *Year 2010* | 0.266 | *** | 0.054 | -0.419 | * | 0.175 |
| **Average Treatment Effect** | | | | | | |
| *T* Year 2001* Ecovía* | -0.207 | * | 0.077 | 0.570 | * | 0.148 |
| *T* Year 2002* Ecovía* | -0.090 | | 0.081 | 0.291 | *** | 0.170 |
| *T* Year 2003* Ecovía* | 0.027 | | 0.084 | 0.354 | | 0.173 |
| *T* Year 2004* Ecovía* | 0.259 | * | 0.083 | 0.557 | * | 0.207 |
| *T* Year 2005* Ecovía* | 0.269 | ** | 0.080 | -0.044 | | 0.164 |
| *T* Year 2006* Ecovía* | 0.454 | *** | 0.072 | 0.416 | ** | 0.144 |
| *T* Year 2007* Ecovía* | 0.450 | *** | 0.070 | -0.155 | | 0.215 |
| *T* Year 2008* Ecovía* | 0.436 | *** | 0.069 | -0.506 | | 0.355 |
| *T* Year 2009* Ecovía* | 0.393 | *** | 0.068 | -1.008 | ** | 0.367 |
| *T* Year 2010* Ecovía* | 0.317 | *** | 0.067 | -1.116 | *** | 0.278 |
| *T* Year 2001* Corredor Norte* | 0.134 | | 0.076 | 0.609 | *** | |
| *T* Year 2002* Corredor Norte* | 0.127 | | 0.075 | -0.103 | | 0.187 |
| *T* Year 2003* Corredor Norte* | 0.236 | ** | 0.074 | 0.277 | | 0.152 |
| *T* Year 2004* Corredor Norte* | 0.272 | *** | 0.072 | 0.007 | | 0.157 |
| *T* Year 2005* Corredor Norte* | 0.191 | * | 0.069 | -0.327 | * | 0.141 |
| *T* Year 2006* Corredor Norte* | 0.237 | *** | 0.064 | 0.049 | | 0.154 |
| *T* Year 2007* Corredor Norte* | 0.263 | *** | 0.064 | 0.140 | | 0.284 |
| *T* Year 2008* Corredor Norte* | 0.248 | *** | 0.063 | -0.430 | | 0.408 |
| *T* Year 2009* Corredor Norte* | 0.219 | *** | 0.062 | -0.620 | | 0.420 |
| *T* Year 2010* Corredor Norte* | 0.153 | * | 0.060 | -0.885 | * | 0.410 |
| **Constant term** | 3.124 | *** | 0.216 | -5.763 | *** | 0.616 |
| | | | | | | |
| N | 135,510 | | | 135,510 | | |
| F (50,135459) | 533.74 | | | -30534.79 | | |
| Prob > F | 0.00 | | | 1007.27 | | |
| R-squared | 0.44 | | | 0.00 | | |
| Root MSE | 2.39 | | | 0.07 | | |

†Wald test of estimated coefficients in relation to the base line coefficient: Treatment*Year2001*Ecovia and Treatment * Year 2001* Corredor Norte ††F statistic: (1,135459)

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

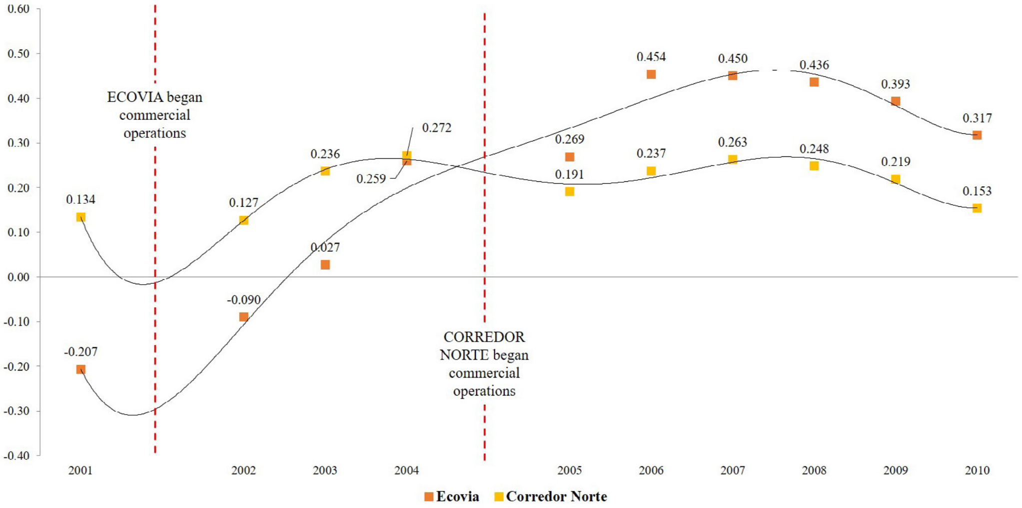


**Figure 6.** Estimated average effect of BRT on built-up area of redevelopments over time by BRT corridor, Quito, Ecuador

Note: 95% confidence intervals not shown for parsimony. Not all coefficients are statistically significant. Refer to Table 3 for statistical significance of estimated coefficients. Polynomial spline shown to describe trend.

### 5.2.3 Impact of BRT on redevelopment

Our results for the BRT system's effect on redevelopment suggest a similar pattern for both corridors over time, although the probability of redevelopment along "*Ecovia*" appears to be greater than it is for "*Corredor Norte*" (Table 5). After the opening of "*Ecovia*" in 2002, the probabilities for redevelopment increased in 2004 (5.64%), 2005 (5.47%), and 2006 (5.16%; Figure 7). The parcels located along "*Corredor Norte*," after the opening of the BRT in 2005, experienced lower probabilities for redevelopment in contrast to previous years (Figure 7). The results regarding the pattern on "*Corredor Norte*" may be related to the fact that the International Airport was formerly situated next to this BRT corridor until 2013, thus it was only after the relocation of the Airport that building height restrictions were removed. The result we obtained for the distance to the CBD suggests that redevelopments become more likely as the distance from the city center increases, and thus, from the Historic Center as well.

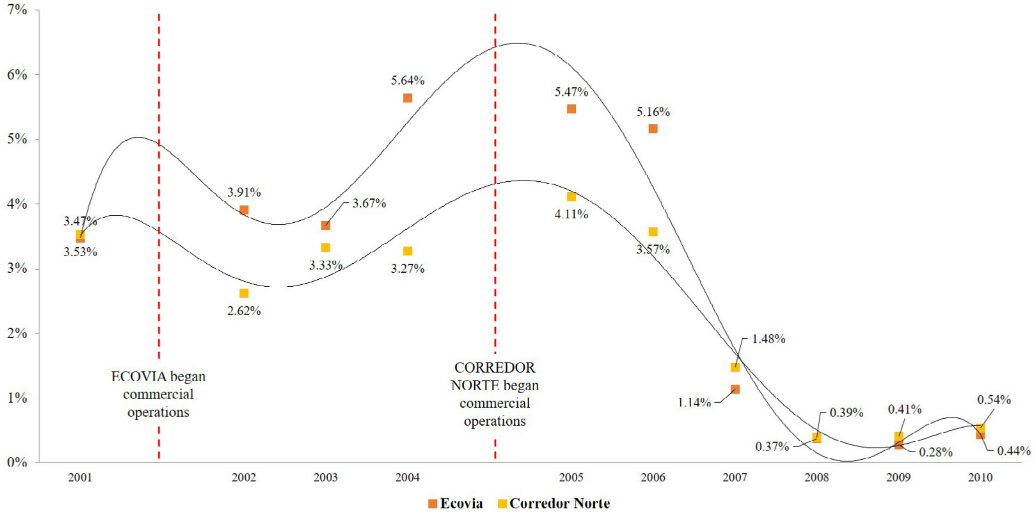


**Figure 7.** Average predicted probability of redevelopment over time by BRT corridor, Quito, Ecuador

Note: 95% confidence intervals not shown for parsimony. Not all coefficients are statistically significant. Refer to Table 3 for statistical significance of estimated coefficients. Polynomial spline shown to describe trend.

## 6 Discussion

### 6.1 Built-up area in Bogotá and Quito

Our analysis of the Bogotá data revealed an increase in built-up area over time but the effect of the BRT system was mixed (Figure 3). The effect along "*Av Caracas*" was larger than in the control areas but with slight changes over time. The effect along "*Autonorte*" was positive and increasing over time, mainly due to the presence of larger parcels with redevelopment opportunities. The effect along "*Av Calle 80*" was less than it was for control areas. These results confirm the challenge of implementing mass transit in already urbanized areas, where development opportunities are more likely to exist at the extreme ends of corridors, where the BRT Terminals "*Norte*," "*Portal 80*," and "*Usme*" were constructed for the first phase of the system (Bocarejo et al., 2012; Vergel-Tovar & Camargo, 2019). Results for Quito are similarly mixed (Figure 6). The pattern of increased activity along "*Ecovia*" is higher than it is for parcels served by "*Corredor Norte*." The development activity along the "*Ecovia*" corridor is related to redevelopment initiatives occurring in parcels intended to extend the city center.

Our results are consistent with findings from other studies in terms of the low or minimal effect the BRT systems had on increasing development (Cervero & Dai, 2014; Rodriguez et al., 2016; Suzuki et al., 2013). This highlights the complexity of implementing mass transit systems along already consolidated areas and major arterial roads, and the importance of land planning in facilitating redevelopment activity along corridors. Considering that our data analysis showed significant cumulative increments over time in the built-up area along *Av. Caracas*, we suggest that those land parcels that experienced significant increments in built-up area are most likely associated with redevelopments since *Av. Caracas* is an already consolidated corridor. However, land parcels in the control areas also experienced significant increments in built-up area compared to *Av Calle 80* and the *Autonorte* (between 2003 and 2005). Our findings also suggest larger numbers of built-up areas have been established within different ranges of distance from current or future BRT stations in relation to parcels located within 100 meters of the corridors. We propose that this relationship is subject to variations not only in terms of time but also of space. Consistent with findings of previous studies in terms of land prices (Rodriguez & Targa, 2004), this spatial heterogeneity suggests that developments take place close to current or future BRT stations with variations according to the parcels' distance to these stations (current and future).

When we compare our results with those of previous examinations of other types of mass transit systems, we find that, in contrast to extensions of new Light-Rail Transit (LRT) corridors in cities like Minneapolis, Denver, and Charlotte, where the number of new developments was considerably higher around stations (Fogarty & Austin, 2011). The built-up area impacts of BRT in Bogotá and Quito occur mainly in areas where development opportunities were available due to significantly higher parcel sizes (*Autonorte* in Bogotá and *Av 6 Diciembre* in Quito). However, we observed similar uneven impacts on deelopment (changes in relation to the BRT stations) as did previous researchers examining he effects of the BART system (San Francisco, California). The BART study reported that multifamily housing developments occurred more frequently in higher density areas and closer to transit stations, but that parcel area and the presence of vacant land were more important predictors of changes in built-up areas (Cervero & Landis, 1997a).

### 6.2 Land use in Bogotá

Our analysis of Bogotá showed related but contrasting BRT effects on residential (Figure 4) and commercial land uses (Figure 5). We found a significant shift along BRT buffer areas towards greater commercial land use. This is unsurprising given the concentration of activity related to BRT and the higher rents that commercial space can yield compared to residential, all else held equal. We also observed that the probability of commercial land uses is greaer within 100 meters of the BRT stations. As expected, impacts were not homogeneous across the three BRT corridors we examined. There are many higher density developments along corridors, but many were likely the result of land assembly of parcels hence were not captured by our data. The smaller likelihood of the establishment of residential land uses is stronger along "*Autonorte*" than in the controls, but parcels in "*Av Calle 80"* were more likely to be put to residential use when compared to controls. The probabilities of commercial land use increased in all three corridors, but the effect was stronger along the "*Av Autonorte*" corridor.

By contrast, residential land-use changes are most likely to occur further away from BRT stations (or future stations, in control areas) than within 100 meters of transit stations; and more frequently in middle-income and upper-income areas than in lower-income areas. This implies a challenge in equity of access to land and housing for low-income groups. However, commercial land-use changes were more likely to occur in lower-income areas than in upper-income areas, specifically in parcels in middle-income neighborhoods (socioeconomic level 3). This finding is also connected to the fact that BRT terminals located at the peripheries opened new development opportunities, most of which have been for commercial use within close proximity to these large transportation hubs. It is important to take these findings with caution given that we analyzed land use at the parcel level, thus the emergence of mixed-use developments is partially reflected in the results.

Our findings are also consistent with land-use impacts of BRT in Seoul, where condominiums and mixed-use buildings were less likely to occur within 100 meters from stations and single family conversions were more likely to occur beyond the 100-meter threshold (Cervero & Kang, 2011). As mentioned previously, our results are similar to those reported for LRT systems, in terms of the timing and the type of land use implemented close to transit corridors. One study reported an increase in commercial development along the original LRT corridor in Houston between 4 and 10 years after the LRT's opening, while the land development along the newest LRT corridor were modest (Lee & Sener, 2017). Another study indicated that land-use changes took place for industrial and residential parcels within a half mile of LRT stations in Minneapolis (Minnesota, USA) during the construction and operational stages of the transit system (Hurst & West, 2014).

Our results highlight the challenges associated with the implementation of BRT systems and their impacts on land-use changes. Our findings suggest that BRT systems can influence land-use changes via the accesibility benefits generated by their stations. These benefits foster opportunities to create nodes of commercial activity. Residential developments might take place close to the stations or in mixed-use developments along the corridors. Policy and planning decisions involving regulations can certainly influence this type of outcome as well. At the same time, real estate markets respond with development projects that generate housing in close proximity to stations, and commercial developments suchas big-box stores might seek to emerge next to the mass transit stations. We recommend that future researhers examine this complexity through qualitative data analysis that may provide further insight into our results.

### 6.3 Redevelopments in Quito

For the control parcels, redevelopment was more likely along "*Ecovia*" in 2001 and 2004 (Figure 6). The probability of redevelopment along "*Ecovia*" increased in 2004 and then decreased over time compared to the control corridor "*Corredor Suroccidental.*" In the case of the "*Corredor Central Norte*," the probability of redevelopments also decreased over time relative to the control corridor "*Corredor Suroccidental*" (Figure 7). This result regarding the pattern on "*Corredor Central Norte*" could be related to the relocation of the International Airport outside the city in 2013, opening opportunities for future redevelopments due to potential changes in building height restrictions.

### 6.4 Propensity score analysis and transit as treatment in Bogotá and Quito

A careful assessment of balance between treatment and control parcels, like the one presented here, appears to be crucial for analyses seeking to capture the effect of mass transit treatments. Achieving balance not only depends on the type and number of variables included—in this case only independent variables—but also the number of observations. The probability of receiving treatment is interesting in its own right. Our estimation of the propensity score using parcel level data from Bogotá and Quito tested a number of assumptions from land use and transportation theory. First, land-use types in Bogotá such as industrial, commercial, and public facilities were more likely to receive mass transit (treatment) than residential land use, partly because they tended to be located in busy arterials. In Bogotá, the presence of vacant units, other use, and mixed-use parcels suggests a smaller likelihood of receiving a transit treatment; however, in Quito, a mixture of land-use types increases the probability of being treated. This result confirms the traditional approach used in transportation planning of providing transit services to those areas with greater concentrations of activities.

An important distinction between Bogotá and Quito is the effect of distance to the CBD and mass transit. Even though in both cases the CBD is the nucleus of fairly monocentric urban spatial structures, the fact that mass transit corridors in Quito converge at the "*La Marin*" transportation hub (next to the Historic Center) suggests that developmental restrictions on central land parcels pushes development away from the city center. The opposite relationship was found in Bogotá, where the closer the parcel to the "*Centro Internacional Calle 26*," the higher the probability of being transit treated. Our estimation of the propensity scores also confirms the key role played by road space in the reception of treatment (transit), a salient feature in the case of BRT systems and exclusive lanes. The propensity scores in Bogotá suggest the effect of a high density of public facilities (main destinations) with respect to being treated.

### 6.5 Limitations

This is one of the first parcel-level data analyses of BRT's land development impacts. However, despite the large number of observations (Bogotá: 98,176 per year, and Quito: 13,551 per year), have several limitations. The first challenge was the implementation of a quasi-experimental study methodology, which took parcels selected for the treatment effect (BRT) and used those parcels that have not yet received this treatment as controls (Bogotá: parcels along "*Av 68*" and "*Av Boyaca*," Quito: future "*Corredor Suroccidental*"). In the case of Bogotá, "*Av 68*" and "*Av Boyaca*", two main arterial roads for which there are no plans to date to use them as BRT corridors, are the best control corridors for our purposes. Nevertheless, the other arterial roads "*Av Caracas*," "*Autonorte*" and "*Av Calle 80*" were selected for BRT first, based on a non-random reason. In the case of Quito, to find a control corridor is even more challenging because all bus rapid transit corridors are already in operation. We took "*Corridor Suroccidental*" considering that it is the most recent corridor to be put into operation, thus leaving a time window that could reveal changes in built-up areas over time.

Finding comparable parcels constitutes a challenge in itself. The propensity score analysis used in this paper overcame this challenge by estimating the probability of receiving treatment of parcels located on trunk corridors of this mass transit system and parcels located along two main arterial roads that have not yet, in the case of Bogotá, been subject to treatment (transit investments). Unobserved differences among parcels in the treated and non-treated areas remain a source of concern. Moreover, the consideration of a future corridor as a control is a positive yet imperfect way of addressing potential selection bias at the corridor level. Another limitation is that the baseline data in Bogotá (2000) was collected in 1999 when the BRT was under construction. In the case of Quito, the baseline data (2001) dates back to one year prior to the start of operations of "*Ecovia*" (2002). There is no data available for Bogotá at this level of detail before the year 2000 nor for Quito from the 1990s. Also, we excluded parcels with missing data which may have introduced bias to our analyses. Finally, interference between treatment and control areas is an issue. The treatment and control parcels are part of the same real estate market in both cities so that there might be some interference from the real estate market in the comparison of the two groups (Cervero & Landis, 1997b).

The data set in both cities could be capturing anticipated effects, if any, of the BRT system on land development, bt this may be true also for other studies on data of land prices and property values. A limitation of the use of time dummy variables in a difference-in-differences model is serial correlation which is addressed using placebo tests (Bertrand et al., 2001). Unfortunately, the dates available for Bogotá and Quito make it impossible to conduct placebo tests with pre-intervention data several years before the intervention of the BRT corridors. In the case of Bogotá, it was not possible to access data before the year 2000. In the case of Quito, given the "dollarization" of the economy in 2000, the data analysis focuses on the period in which the US dollar was the official currency in its economy. This data availability issue also implies a limitation of measuring anticipatory effects. The literature on BRT is limited in this regard but one study indicated no anticipatory effects on land prices with the announcement of a BRT corridor in Mexico DF (Flores Dewey, 2012).

Another limitation of our results is the buffer area. In the literature, different catchment areas have been used to test the effects of mass transit systems on the built environment. Given the intersection of some of the treatment and control corridors used in this study, the buffer area of 500 meters on both sides of the corridor (1km in total) was determined as the most convenient area of analysis for our analysis in both cities to avoid additional overlaps. However, we sought to address this limitation by including the distance to current and future BRT stations beyond 500 meters. Future researchers could include a 1km buffer area to determine the extent by which transit investments could affect development and land-use change at longer distances than the ones we used. Another limitation of our data bases is that the Cadaster Department of Bogotá provided information regarding the land uses at the land parcel level, but we do not have an assessment of mixed-use developments, thus we recommend that future researchers estimate the potential effects of the implementation of mass transit systems on mixed-use developments. Finally, in a local transit network that includes additional services (integrated, unintegrated but formal, and informal), the characterization of these services and the inclusion in the statistical analysis is difficult thus our analysis focused on the spillover effects of BRT lines but not on those of local transit networks. However, our data analysis controls for the distance to activity nodes which is related to the transit coverage in our case studies.

We also acknowledge that our control areas may have been affected by the intervention and therefore our results may be biased (Shadish et al., 2002). We sought to address concerns about external validity by carefully obtaining information to satisfy the parallel trend assumption implicit in a difference in difference research design. Still, if the control group is affected by the intervention, this assumption would be violated. Furthermore, although we examined two cities with known physical differences and similarities, it is clear that our results are largely contextual thus subject to local historical, political, and economic factors.

## 7 Conclusions

Land use and development impact studies often require detailed parcel-level data, which is usually difficult to obtain and process. Also, the study of changes in the built environment in terms of development and land uses requires a time window of at least several years to observe changes, especially in already urbanized areas. This is a key difference between the study of the impacts of land use and development and the study of property and land prices. Most studies of BRT impacts have been focused on property and land prices. We used longitudinal parcel-level data to examine the land use and development impacts of a BRT system over time in Bogotá and Quito, comparing them to provide policy recommendations for other cities implementing BRT systems.

In Bogotá, we found that the built-up area of the first phase of the BRT had very limited effects on the built area along one corridor ("*Av Calle 80*"), but a positive effect along two other corridors ("*Av Caracas*" and "*Autonorte*") in relation to the control areas ("*Av 68*" and "*Av Boyaca*"). We also found a positive effect with respect to the conversion to commercial uses, mostly along one treatment corridor ("*Autonorte*"). In Quito, we found mixed results from the average treatment effects of BRT on new built-up areas. Along the "*Ecovia*" corridor, the increase in new built areas was greater than the "*Corredor Central Norte*" after 2005. These redevelopments along the BRT corridors in Quito are not homogeneous in terms of location and space, as they are in Bogotá. Our findings regarding redevelopment suggest significant spatial heterogeneity. In particular, development tends to cluster in close proximity to stations, but not immediately next to the corridor.

Based on our findings, we propose a set of recommendations. First, we recommend the implementation of BRT systems as urban development projects integrating land use and transportation. Our findings regarding the differences in built-up areas at different distances from BRT stations (current or future) also suggest how these impacts are scattered in a city, in the absence of a transit-oriented development policy, in response to attributes such as parcel size and regional accessibility. Both cities have experimented in the implementation of innovative transportation systems but the lack of evidence regarding the land-use impact of BRT systems has made it difficult to change the mindset of decision makers regarding BRT systems as land-use tools.

Second, we suggest that BRT systems should be considered as a land-use tool that influences the conversion of parcels to other uses as a result of their distance to BRT stations. One of our key findings in Bogotá was the positive impact of the BRT system on land-use conversions to commercial uses. As has been discussed in the Latin American planning community, land-use changes constitute a key factor for land value increments and for value capture mechanisms. However, given that we are not measuring variables associated with land values, we recommend further research into value capture assessments associated with commercial land uses around BRT stations.

Further analyses of the spatial heterogeneity we identified seem warranted. Other researchers can test hypotheses on the impacts of BRT systems on built-up area per land-use type. Similarly, the timing of transit impacts on land use and development has been a subject of study for rail-based systems but there are no studies assessing this relationship in the case of BRT systems. The importance of when the changes happened appears to be a worthwhile factor to investigate.

Another recommendation for further work involves the examination of land use and development impacts of the second and third phases of the BRT system in Bogotá, following the same methodology we developed. The second and third phases of the BRT in Bogotá were implemented using different approaches, widening the intervention of the road section from façade to façade including the improvements of sidewalks, squares and other public space features. This constitutes a large contrast with the novelty factor of the first phase of BRT in Bogotá considering that no one knew much about the type of mass transit system that was going to be implemented. We also recommend the analysis of the impact of the "*Trolebus*" corridor in Quito depending on the availability of parcel-level data for the period before 1996.

With more than 170 cities worldwide in the process of planning, expanding, or operating BRT systems, understanding the impact of such systems on shaping urban development becomes an important task. Existing empirical studies on the potential of BRT systems to shape cities and change urban form are limited. Our findings suggest that the inclusion of an equity perspective in the relationship between BRT and the built environment is an important perspective that needs to be taken into account to make cities more accessible environmentally, as well as socially equitable and inclusive.

## Acknowledgments

This research received support from the Institute of the Study of the Americas and the Department of City and Regional Planning at the University of North Carolina at Chapel Hill. In Bogotá, this research received support from the Departamento Nacional de Planeacion DNP, Secretaria Distrital de Planeacion SDP, Unidad Administrativa Especial de Catastro de Bogotá, Transmilenio SA, Gustavo Marulanda, Ivan Herrera Sanchez, Laura Carrillo Leon, Ivan Cano, Mario Leonardo Nieto, William Camargo, Nicolas Estupiñan and Maria Cristina Rojas. In Quito, this research received support from the Secretaria de Territorio Habitat Vivienda STHV, Empresa Metropolitana de Transporte de Pasajeros de Quito EPMTPQ, Dirección Metropolitana de Catastro, Rene Vallejo, Fernando Puente, Monica Quintana, Carlos Poveda, Jose Tupiza, Fabricio Castillo, Henry Vilatuna, Sandra Hidalgo, Marcelo Yánez, Paco Salazar, Ivonne Vimos, Daniel Hidalgo, Mario Recalde, Carmen Andrade and Luis Suarez.

## Appendix

Appendix: Supplemental materials available at https://www.jtlu.org/index.php/jtlu/article/view/1888.

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