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Working Paper

Do bus rapid transit systems improve accessibility to job opportunities for the poor? The case of Lima, Peru

IDB Working Paper Series, No. IDB-WP-977

Provided in Cooperation with:

Inter-American Development Bank (IDB), Washington, DC

Suggested Citation: Oviedo, Daniel; Scholl, Lynn; Innao, Marco; Pedraza, Lauramaría (2018) : Do bus rapid transit systems improve accessibility to job opportunities for the poor? The case of Lima, Peru, IDB Working Paper Series, No. IDB-WP-977, Inter-American Development Bank (IDB), Washington, DC, <https://doi.org/10.18235/0001525>

This Version is available at:

<https://hdl.handle.net/10419/208167>

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Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Do Bus Rapid Transit Systems improve accessibility to job opportunities for the poor?:
the case of Lima, Peru / Daniel Oviedo, Lynn Scholl, Marco Innao, Lauramaria
Pedraza.

p. cm. — (IDB Working Paper Series ; 977)

Includes bibliographic references.

1. Bus rapid transit-Peru. 2. Urban transportation-Peru. 3. Poor-Employment-Peru. I.
Oviedo, Daniel. II. Scholl, Lynn. III. Innao, Marco. IV. Pedraza, Lauramaria. V. Inter-
American Development Bank. Office of Strategic Planning and Development
Effectiveness. VI. Inter-American Development Bank. Transport Division. VII. IDB
Invest. VIII. Series.
IDB-WP-977

<http://www.iadb.org>

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Do Bus Rapid Transit Systems improve accessibility to job opportunities for the poor?

The case of Lima, Peru*

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December 2018

Abstract

Investments in public transit infrastructure in Latin America and the Caribbean often aim to reduce spatial and social inequalities by improving accessibility to jobs and other opportunities. The Metropolitano, Lima's Bus Rapid Transit (BRT) project at inception, had, as one of its central goals, to connect low-income populations living in the peripheries to jobs in the city center. We examine the contribution of Lima's BRT system to accessibility to employment in the city, particularly for low-income public transit users. We build on secondary datasets of employment, household socio-demographics and Origin-Destination surveys before and after the BRT began operations to assess its effects on potential accessibility to employment. Findings suggest that the BRT line reduced travel times to reach jobs, in comparison with traditional public transport in the city, amongst populations living within walking distance of the system. However, we also find that the coverage of the BRT is minimal in areas with high concentrations of poor and extreme poor populations, limiting the equitability of the accessibility improvements. We present a reflection on the distributional effects of BRT infrastructure and services, discussing policy avenues that can improve the prospects for BRT system investments to include the poor in their mobility benefits.

Keywords: Bus Rapid Transit; employment; accessibility

JEL Codes: J01, J21, R41

* The authors would like to thank an anonymous reviewer for useful comments on an earlier draft of the paper, and Oscar Mitnik (IDB) and Patricia Yanez (IDB) for their helpful comments and suggestions during the development of this research project. We also want to thank Orlando Sabogal for his support on data management and calculations for the accessibility analysis and Rafael Capristan (IDB) for his support with meetings and interviews with relevant government authorities and in procuring access to key data for this research. The Inter-American Development Bank (IDB) provided funding for this project through the ESW RG-E1502. The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the IDB, IDB Invest, their Boards of Directors, or the countries they represent.

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1. Introduction

Bus rapid transit (BRT) systems are recognized in international policy circles as efficient, cost-effective, public transport solutions for cities facing mobility challenges associated with rapid urbanization and motorization, particularly in cities of the Global South. BRT systems have been implemented in various cities across Latin America, searching to restructure transport networks to improve of operational inefficiency and address large levels of informality in public transport services. Such systems typically aim to increase overall mobility while also reducing negative externalities such as traffic accidents and emissions of local and global pollutants; in addition, they often seek to improve mobility and access to jobs, goods, and services for the poor.

The extent to which the poor and vulnerable groups are included in these benefits is a growing area of research relevant to objectives of promoting social inclusion while fostering environmentally sustainable economic development. Low-income populations often bear the highest burdens related to negative transport externalities in cities, including longer travel times, and higher exposure to pollution and risk of traffic accidents. Lack of access to affordable and efficient transport generates social exclusion, impeding access to employment opportunities, services, and markets. As poor populations often live on the periphery of Latin American cities, they tend to have the longest travel times and to incur more transfers, generating high transport costs to reach employment opportunities.

Reduced travel times to reach destinations within a city afforded by investments in faster and more efficient public transport can make previously inaccessible job markets accessible, within given monetary and time budgets, thereby increasing the likelihood of formal employment, increased income and potential accumulation of assets for populations living within the area of influence of the systems. However, little research exists on the extent to which these benefits are realized and what policy measures are needed to improve the distributional outcomes of such transit investments, particularly in the developing country context.

In 2010 the first BRT corridor began operations in Lima, Peru. One of the key objectives of the project was to connect low-income populations living in the far-flung outreaches of the sprawling and congested metropolitan area to jobs in the center. Prior to the opening of the line, the corridor, and city was plagued by an oversupply of polluting and unregulated minivan transit providers, leading to lengthy commutes of up to 2 hours in each direction for those living in the periphery. Although prior research on the system has found that the system carries a fair number of lower income groups, coverage in areas in extreme poverty is limited. Nevertheless, the poor and

extreme poor tend to use the system for longer trips and to reach work or education. In this paper, we assess the extent to which Lima's BRT system increased access to employment measuring potential accessibility and the spatial distribution of opportunities in the city.

Utilizing data on employment, socio-economic status, and other demographic variables at the household level before and after the BRT system we assess the effects on accessibility to employment for lower income groups. We hypothesize that reduced travel times of Lima's urban poor living near BRT stations and feeder lines, because of the project, may increase access to a wider array of opportunities and jobs, leading to increased rates of employment, and an overall reduction of generalized costs of travel, which may support economic affordability and alleviate time poverty. We analyze the spatial distribution of opportunities for employment in Lima and how these patterns are influenced by land-use and other features of the city. Next, we explore the changes in potential accessibility to employment opportunities attributable to the BRT in low-income areas of Lima. Finally, we discuss policies to improve the prospects for BRT system investments to include the poor in their mobility benefits through increasing the understanding of factors that contribute or impede access to employment via mass transit. The results of this analysis draw lessons for future urban transport projects aimed at improving mobility and accessibility for the urban poor.

Results from the analysis suggest that, overall, the BRT line, in comparison with traditional public transport in the city, reduced travel times to reach jobs amongst populations living within walking distance of the system. However, we also find that the coverage of the BRT is minimal in areas with high concentrations of poor and extreme poor populations, limiting the equitability of the accessibility improvements. Our scenario analysis of the accessibility gains in the system suggests reductions in travel times for trips longer than 6 km. Such trips are usually made by the poor. Given that the system is the first of several planned lines, it carries a small fraction of the total city's public transit demand, limiting the role of the system in containing otherwise generalized increase in travel costs for work trips by public transport.

2. Background

Although over 72 million people in the Latin America and the Caribbean region have transitioned out of poverty and nearly 94 million have joined the middle class, since 2003, 42% of the region's population (140 million) still live in economic poverty, while nearly 67 million people are below the poverty line of US\$2.5 per day. In Latin American cities, poverty tends to be concentrated in peripheral areas far from jobs and other economic activities. From 1950 to 2014, the share of the

population in Latin America living in urban areas increased from 40% to around 80% and is expected to increase to 90% by 2050 (Atlantic Council, 2014). This spatial segregation of the poor from skill-appropriate job centers has been theorized to decrease the affordability of job search and access, and thus increases unemployment (Kain, 1992). This restricted access to a wider job market may in turn contribute to the persistence of poverty by reinforcing the restrictions on the availability of resources and disposable income for household travel.

People experiencing economic poverty often must negotiate the allocation of limited disposable income for transport and other essential needs, which can significantly reduce their mobility and accessibility to employment, education and other relevant social and cultural opportunities such as education, leisure and healthcare. This may in turn hinder their ability to accumulate assets needed to overcome poverty. As low-income populations are often captive users of public transport or rely on non-motorized travel because of affordability barriers, travel expenditures can consume 30% or more of daily wages of the poor, adding to the already-high travel time costs, which in some cases can exceed two hours (Kalthier, 2002; Vasconcellos, 2001).

Data from the Development Bank of Latin America (CAF) (2012) shows that in the largest 15 metropolitan areas in Latin America people consume 1.1 hours per trip per day, which adds to over 118 million hours per day. However, the distribution of travel times is not uniform across social groups. By being farther from the city center, lower income citizens, who are the social group that uses public transport the most, are forced to experience longer travel times because of larger distances, congestion, and often poor local coverage of public transport that requires long walking times to bus and train stations. For example, while bus users spend on average 58.8 minutes per trip, car users in the region spend on average 25.5 minutes per trip (CAF, 2009). These longer trips and excessive walking and travel times can result in time deprivation for opportunities such as higher education, as well as leisure and, in some cases, social interactions (Oviedo and Titheridge, 2016).

Higher travel expenditures and long travel times can also often lead to immobility and social exclusion among vulnerable members of poor households, as resources are prioritized to pay for work, or income generating trips. For example, transit users buying up to 50 tickets per month can spend up to 20% of their income, while car users tend to spend on average below 10% (Bocarejo & Oviedo, 2012; CAF, 2012; Cervero, 2013; Falavigna & Hernandez, 2016; Hidalgo & Huizenga, 2013). As a result, the poor tend to sacrifice trips, with the majority of the poor in the cities of developing countries make on average between one-fifth and one-third fewer trips per capita than the non-poor (Bocarejo & Oviedo, 2012; CAF, 2012; Cervero, 2013; Gakenheimer,

1999). This can reduce available resources among non-working household members for travel, who may also suffer from acute time poverty, since they assume more household responsibilities such as home making and caring for children and the elderly (Oviedo and Titheridge, 2016).

Finally, gaps in infrastructure supply and quality can exasperate the barriers created by spatial gaps between housing and jobs. Although there are approximately 245,000 km of roads available for circulation in metropolitan areas of Latin America (17km/km²), their quality is precarious in most cities (CAF, 2012). In addition, public transport modes tend to have lower priority in the allocation of road space (Hidalgo & Huizenga, 2013), with between 98% and 99% of total road space in cities of Latin America being dedicated to private vehicles and scant provision of exclusive roads for pedestrian circulation, which in the region represents only 0.4% of built infrastructure (CAF, 2012). Higher quality road infrastructure in good condition, and preferential pedestrian and cyclist spaces, tend to be concentrated in and around the Central Business Districts (CBD) of the different metropolises and higher income neighborhoods, while most of the damaged and unsurfaced roads are in low-income (and often peripheral) areas (CAF, 2012; UNCRD-IDB, 2012).

2.1 Accessibility: Policy relevance, concepts, measurement, and the links with social exclusion

The concept of accessibility has occupied an increasingly relevant position in modern urban transport theory and practice, leading to a change in urban policy objectives throughout the Global North and South (UN-HABITAT, 2013). The new agenda for sustainable development recognizes the transformative role of cities as catalysts for the development of not only more sustainable societies, but ones that can be more inclusive and resilient (UN-HABITAT, 2016). Such agenda does not only recognize the role of cities in human development, but also the role of transport in urban development, social equity and inclusion. As reflected by the Sustainable Development Goal (SDG) number 13.1, it is aimed that by 2030 cities throughout the world provide “**access** to safe, affordable, **accessible** and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons” (UNDP, 2016).

Measuring accessibility can be a key factor in equity analysis, for example when evaluating the distribution of access benefits of new transport systems across income or spatial groups (Bocarejo and Oviedo, 2012; Fan, Guthrie and Levinson, 2010; Manaugh and El-Geneidy, 2012). Its measurement requires robust definitions of accessibility and adequate data to measure the characteristics and expected benefits of such interventions.

Nearly all accessibility definitions and measurements consider the potential range of interactions within transportation networks and the spatial and economic constraints of movement within an urban area. Definitions of accessibility in the literature range widely and include: the potential opportunities for interaction (Hansen, 1959), the ease of reaching areas of activities within a given transport system (Dalvi & Maritin, 1976), and the overall benefits provided by a given transport system (Ben-Akiva & Lerman, 1979). More recent literature defines accessibility as the ease of reaching desired destinations and available opportunities, given available resource constraints for travel (Bocarejo & Oviedo, 2012). Framing the concept at different scales, from individual to neighborhoods and communities, van Wee, Geurs & Chorus (2013) identify four components of accessibility: land-use, transportation, temporal, and individual:

The land-use component: Encompasses the land-use system, which includes: (i) the number, quality and spatial distribution of opportunities available at each destination (i.e. jobs, shops, health, social and recreational facilities, etc.); (ii) the demand for these opportunities from residential locations (origins); and (iii) the interaction between demand and supply for opportunities, which could lead to competition for activities with restricted capacity such as jobs, school vacancies and hospital beds (Van Wee, Hagoort, & Annema, 2001).

The transportation component: Corresponds to the transport system, which is interpreted as the disutility associated to the distance between an origin and a destination for an individual using a specific transport mode. Such disutility considers the amount of time (travel, waiting and parking), economic costs (fixed and variable) and effort (including reliability, comfort, risk of accidents, etc.) that come from confronting transport supply and demand. Supply of infrastructure includes its location and characteristics (e.g. maximum travel speed, number of lanes, public transport timetables, travel costs), while demand encompasses both passenger and freight travel demand.

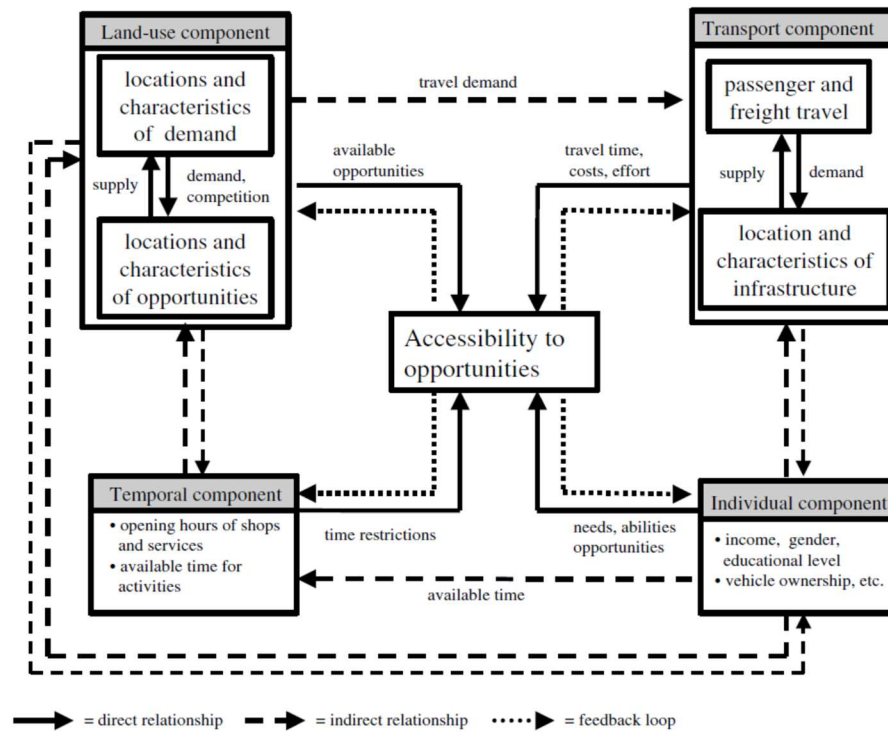
The temporal component: Is associated with time restrictions for making use of opportunities. For example, the availability of opportunities at various times of the day as well as the availability of time for individuals to participate in activities such as work and recreation.

The individual component: The individual component reflects differentiated needs by individual characteristics (e.g. age, income, educational level, household situation, employment status etc.) and abilities (such as people's physical condition, availability of travel modes, etc.). Such individual features can influence people's level of access to modes of transport (for example, ability to drive or borrow a car), and the opportunities distributed in space (e.g. match of abilities

required for certain jobs in proximity to the area of residence), which can in turn constrain accessibility. Research suggests that accessibility to employment is significantly affected when competition factors, understood as the matching between abilities, education and experience between an individual and a given job position, are incorporated in the estimation of accessibility indicators (Geurs & Ritsema van Eck, 2001; van Wee et al., 2001). The interaction between these components is argued, in turn, to influence access. For instance, the distribution of activities in space (land-use) is a determining factor in travel demand (transport), and it can also produce time constraints (temporal) and influence people's opportunities (individual).

The linkages between better connectivity brought about by investments in transport infrastructure (transport), the subsequent consolidation of land uses, and changes in land market (accessibility surplus), act together to influence the distribution of activities and travel costs along the land-use, transport and individual components of accessibility. Additionally, urban transport interventions can foster significant changes in access to social and economic opportunities available in cities and, in turn, can affect travel demand, influencing performance and capacity requirements of transport infrastructure and services (Ortuzar & Willumsen, 2012). Finally, the individual component interacts with other determinants of accessibility because they may affect the subjective interpretation and valuation of the variables considered in transport disutility, preferences for activities and the availability of time for specific activities.

Figure 1 - Components of accessibility



Source: van Wee & Geurs, 2012

Various measures of accessibility have been developed to assess these potential interactions between the cost of travel and opportunities (Páez, Scott, & Morency, 2012). Infrastructure-related measures link the effects of transport infrastructure and services over the connectivity of people and activities (van Wee et al., 2001). Activity-related measures account for land uses and the locations of opportunities, estimating the number of activities that can be reached within a given range of travel cost. Gravity measures are a variation of location-based accessibility (Geurs & van Wee, 2004), which are calculated from the perspective of origin zones to all other zones of the area of study. Measuring accessibility requires data on generalized travel costs, demand characteristics such as number of households, job clusters, commercial activities, and origin-destination interaction.

Van Wee et al. (2001), define three main types of accessibility measures: infrastructure-related, activities-related and mixed approaches:

- **Infrastructure-related measures:** The first approach to measuring accessibility focuses on characteristics of transport supply and demand. This type of indicator focuses on the transport component of accessibility. This approach is linked to the

effects of transport infrastructure and services on the connectivity of people and activities.

- **Activity-related measures:** These are linked with land uses and location of opportunities of diverse types, giving attention to the number of activities that can be reached within a given range of travel cost. Activity-related measures, also known in the literature as location-based accessibility, focus on the assessment of the quantity of opportunities and their characteristics within reach from a given origin location. Examples from this perspective include contour measures and potential measures. The contour measure (also called cumulative opportunities), simply counts the number of opportunities available in a certain catchment area of locations, an example being the number of jobs, hospital beds or schools accessible from housing locations within 30-minute travel time. An alternative measure is the potential (or gravity-based) accessibility measure developed by Hansen (1959). This formulation is conceptually linked to Newton's law of gravity and states that the accessibility at point 1 to a particular type of activity at area 2 (jobs, shops, and so on) is directly proportional to the size of the activity at area 2, and inversely proportional to some function of transport impedance (measured in time, distance, or generalized transport costs) separating point 1 from area 2. This is a more behaviorally sound measure than the contour measure as it expresses that more remote locations contribute less to the accessibility indicator than locations close by.
- **The mixed approach:** This approach is the result of combining features of the aforementioned measures. These indicators are generated as a result of an increasing interest in developing comprehensive methodologies that consider both transport supply and the spatial distribution of cities and people. Some authors who have used this kind of methodology have developed more complex measures that seek to better understand the interactions between land-use and transport in terms of their impact on accessibility (i.e. Curtis, 2008; Levine & Garb, 2002; S. D. Nutley, 1980; S. Nutley, 2003; Straatemeier, 2008; van Wee et al., 2001; Wu & Hine, 2003).

Although accessibility is considered part of the 'social approach' to transport analysis, land use and transport models have considered the role of accessibility in location choices from their earliest development. Microsimulation models and computational tools have been developed in recent years in order to estimate the effects of accessibility at different scales and for specific groups. See for example (Preston & Rajé, 2007; Shen, 2015; van Wee & Geurs, 2012; van Wee et al., 2013).

Accessibility-oriented transport planning focuses on the role of transport as an enabling agent to reach destinations where needs can be met, opening the door not only to better transport planning but also to interventions in terms of location and proximity, as well as communication and 'electronic connectivity' (UN-HABITAT, 2013). Thus, policies and urban planning that foster accessibility entail the consideration of a myriad of factors from street characteristics and barriers to network arrangements and efficient public transport development. In this regard, the concept of accessibility, from a policy perspective, encourages multi-modal solutions with larger considerations for individual and collective conditions for mobility, paying special attention to vulnerable groups such as the elderly, disabled and poor.

2.2 Literature review

Several studies have examined the impacts of transport investments on accessibility with a focus on equity in Latin American cities, finding that transport access is highly unequal among socioeconomic groups. For example, Bocarejo and Oviedo (2012) found for the city of Bogotá that high-income populations had potential access to one or more employment positions per inhabitant at costs equal or below their preferred expenditure, while the poor had access to 0.2 to 0.5 jobs per inhabitant even when expending more than their desired budgets for time and money to invest in transportation. Another study found that low-income homemakers and employed women in Recife, Brazil, walk up to 2 km for accessing shopping, 1.2 km for education, 1.5 km for healthcare and 4.3 km for work. In Montevideo, Uruguay, Hernandez and Roseli (2015) found that long waiting times for public transport and high tariffs prevent low-income families from accessing adequate healthcare for their children, and that peripheral households tended to trade-off distance for cost in choosing where to address their healthcare needs.

While some have estimated changes in access to work opportunities from BRT systems, very few studies to date have estimated the effect on labor market participation in Latin American cities. Some examples include research on the impact of accessibility, both to BRT stations and to travel destinations through the BRT. The proximity of BRT routes to the residential location of low-income communities strongly affects equity impacts of accessibility gains. Most trunk routes are initially deployed along high-volume corridors in and near city centers, where they tend to serve older, better-off neighborhoods better. For example, the first phases of the *Masivo Integrado de Occidente* (MIO) BRT system of Santiago de Cali (Colombia) covered only 9% of city districts, located mostly in the central parts of the city (Jaramillo et al., 2012), and skewing benefits in favor of the middle and upper-middle strata (Delmelle and Casas, 2012).

Other literature has examined impacts of BRT on accessibility gains, finding that they depend not only on access to BRT infrastructure, but also on destinations reachable via the BRT. For example, various studies have measured significant gains in accessibility of poor workers to jobs located in central employment areas, especially where BRT systems significantly reduce travel times compared to previously congested or informal services, like in the case of Bogotá (Bocarejo and Oviedo, 2012; Bocarejo, Portilla and Meléndez, 2016; Hidalgo and Yepes, 2005). In the US, some studies have found positive impacts of transit investments on employment outcomes among inner-city youth (Holzer et al., 2003) and among transit-dependent populations (Sanchez, 1999; Tyndall, 2015). Nelson (2017), found for a sample of twenty-three transit systems in the US in three categories (light rail transit, BRT and streetcar transit) that BRT increased regional job-share within 1.5 miles when developed as part of a Transit Oriented Development (TOD) policy, while light rail-based systems had an effect only within 1 mile.

2.3 Urban Transport and Poverty in Lima, Peru

Lima, the capital of Peru, is one of the fastest growing urban areas in Latin America. Its population of slightly above 9.9 million¹ represents about one-third of the population of the country.² Between 2007 and 2012 Lima's population increased by 11%. General trends of economic growth in Lima and Peru have led to a relatively stable increase in individual income since 2007. The distribution of socio-economic groups reflects historic development patterns of Lima. New rural migrants typically settled in the urban periphery while the middle-class and elites moved to the city center (Sabatini, 2003). Today, Lima's low-income population still live mainly in the periphery of the city in the northern and southern cones, while high-income populations are concentrated in the central and south-central areas of the city. Forty-two percent of the extreme poor (Stratum E) and 19% of the poor population (Stratum D) live at least 9 km from the city center. The extreme poor also frequently live in informal settlements characterized by a general lack of infrastructure and public services (Calderón, 2013).

Many low-income neighborhoods are outside the immediate area of coverage of the mass transit lines in the north and west of the city.³ In 2014, 11.5 million Peruvians (72.8%) were directly or indirectly involved in informal employment, with 8.8 million (55.9%) working within the informal sector and 2.7 million (17.0%) working as informal workers in the formal sector (CPLAN, 2016).

¹ <https://www.inei.gob.pe/prensa/noticias/cerca-de-10-millones-de-personas-viven-en-lima-metropolitana-8818/>.

² The city, as defined by the INEI, includes the urban population of the provinces of Lima and Callao.

³ GIS analysis for this study using data from INE, 2007 (also see Annex II).

Lower-income groups in Lima tend to have longer travel times and higher comparative rates of public transit use. They have lower per capita vehicle ownership rates and make the largest share of their daily trips on foot—28% of trips in Stratum D and 35% in Stratum E—followed by trips on traditional buses⁴ (analysis of JICA, 2013). Public transit services in the traditional system encompass a mix of formal and informal supply. Approximately 30% of public transit services are categorized as informal (or unregulated), which is associated with poor service quality as well as high levels of traffic accidents and air pollution (Bielich, 2009).

Lima's BRT project, "El Metropolitano", was the first line of a city-wide mass transit solution planned for the city. The corridor comprises 28.6 km of segregated busway connecting the northern and southern areas of Lima with the financial district, major universities, and the city's historic downtown. The line also integrates feeder routes that extend up to 14 km and connect the two terminals with the surrounding and primarily low-income neighborhoods in the north and south.

The system opened (in 2010) with only 22% of the planned articulated buses and five feeder routes in operation due in part to low demand and unfinished infrastructure (Protransporte, 2014). A year and half later (mid-2012), only 64% of the trunkline fleet was operating. Reforms that impacted service quality and demand, such as the reorganization of existing bus routes and removing direct competitors from the corridor were also significantly delayed.⁵ Moreover, the tariff policy was restructured several times to attract more demand from the feeder areas.

Despite the initial implementation challenges, the system has improved over time, expanding the fleet of buses and the number of feeder lines and seeing substantial corresponding increases in passenger demand. Ridership grew from just under 200,000 passengers per day in the first year to over 600,000 per day in 2016. By 2013 it also achieved its design goal of 60% of ridership of lower and middle socioeconomic strata, however, the share of ridership by poor and very poor (43%) people is lower than that from the middle class (57%).⁶ Although usage by the extreme poor is lower than the poor and middle class, a recent study of the system found that BRT is much more likely (12.4 percentage points more) to be used among lower income groups when making

⁴ Traditional buses include Combis, Colectivos, Omnibus and Microbus which are types of informal and traditional collective transport vehicles that range in size (e.g. a combi is an informal mini-bus, while an omnibus is a larger bus with capacity to carry 90 passengers or more).

⁵ The administration's zero-impact policy and several agreements between bus owners and the municipality stalled the removal of the competing service.

⁶ The demand for the Lima BRT system has been growing steadily since the system opened; it currently carries approximately 550,000 passengers a day (JICA, 2013).

a trip for work or education purposes, indicating that users are willing to pay more for income- (or future income-) generating trips (Scholl, et al., 2017).

3. Data

We estimate the impacts of BRT systems on access to work utilizing available data on economic activities, socio-economic status, and other demographic variables at the household level or at the smallest geographic level available before and after the BRT system. We utilize data from the 2004 and 2012 Lima Metropolitan travel surveys (JICA, 2014 and JICA, 2005), which includes geo-referencing coordinates on the location of surveyed household which allows the estimation of the distance of households to the nearest BRT station, and the 2008 Economic Census from the National Institute of Statistics and Information (INEI, in its Spanish Acronym), which contains information on 1.43 million jobs in Lima, distributed in over 358,000 (formal) firms.⁷ The travel survey data includes detailed household surveys on household characteristics, travel patterns, including stated travel times and monetary costs, employment status in 2004, before the BRT for the Lima-Callao Metropolitan area, and after the BRT began operating (July of 2010). Data from the economic census enables a general analysis of the spatial distribution of the formal job market in Lima, which will be used as a proxy for the distribution of the overall employment supply. Although data on informal jobs locations is not available, it may serve as a proxy for informal activities, as the literature suggests a high correlation between locations of informal activities and large clusters of formal opportunities (Boisjoly, G et al., 2017). As job location information is available only for the year 2008, an analysis of the evolution of the job market throughout Lima is not possible. Finally, we map the locations of opportunities and services in the city relative to housing locations using geocoded data from the Lima's Plan Metropolitano para Lima y el Callao -PLAM- 2035.

4. Methodology

We use a three-step method to measure accessibility changes associated with the BRT investment in Lima that includes the characterization of individuals and opportunities, and an estimation of potential accessibility. To examine how the configuration of land use and transportation infrastructure in Lima impact accessibility we conduct a spatial analysis of the coverage of employment as a percentage of the total land use areas in the city within four

⁷ According to INEI, the Economic Census only accounts for formally constituted firms. Databases of informal employment were not available at a representative scale for the city level.

catchment areas of BRT. Utilizing the 2008 economic census, we produce a heatmap⁸ of the blocks with the higher concentration of jobs in Lima (400 jobs or more). Four buffers were defined for this analysis to have a better understanding of land-use changes with increasing distances from the mass transit lines. The defined distances are 500 meters (equivalent to approximately 5-10 minutes walking), and 1,500 meters (equivalent to 15-20 minutes walking).

Next, the impacts of the BRT on accessibility to employment for social and transport disadvantaged groups compared to non-disadvantaged groups are estimated. Specifically, two approaches for the estimation of location-based accessibility to employment are considered: distance decay function and potential (gravity) accessibility. As the research is concerned with the evolution of accessibility to employment attributable to the Metropolitano, indicators are estimated and compared between two years (2004 and 2012) and between control and treatment groups.

Our accessibility measure is based upon an origin-based distance decay function, following the approach suggested by Bocarejo & Oviedo (2012). This method considers the distance to jobs, weighted by the attributes of a location -in this case measured in terms of their supply of opportunities-, and estimates the potential accessibility to opportunities from a zone (i), to all other areas (j), considering that fewer or farther opportunities are less attractive or more difficult to reach. We compare the measure in areas with and without access to the Metropolitano and control for changes in travel patterns, economic growth, and spatial re-configuration of opportunities by maintaining employment constant in the baseline year and assessing only those trips for which there is information before and after implementation of the system.

Treatment areas are defined as areas within 1,000 m and 1,500 m, approximately 15-20 minutes walking distance, of the BRT system.⁹ The accessibility indicator for public transit trips for a given area, where accessibility increases in direct proportion to the number of opportunities and decays exponentially with generalized travel costs to reach those opportunities, as follows:

$$A_i^m = \sum_j O_j e^{-(\beta_i^m \cdot c_{ij}^m)} \quad (1)$$

where A_i^m is the total potential accessibility from travel analysis zone i using a given public transport mode, m, to all other zones j; O_j represents the number of employment opportunities in

⁸ Heat mapping is a method of showing the geographic clustering of a phenomenon. Heat maps show locations of higher densities of geographic entities.

⁹ Our analysis of the 2012 travel survey data walk access times shows that 99% of passengers walk no more than 20 minutes and 90% walk 12 minutes or less to reach the BRT system (analysis of JICA OD survey, 2012).

each destination zone j , and C_{ijm} is the generalized travel cost between zones i and j for mode m , and β_{im} is a calibration parameter by origin zone and transport mode m . The term generalized travel costs, C_{ijm} , expressed in minutes, can be decomposed as follows:

$$C_{ij}^m = t_{ij}^m + c_{ij}^m / VOT \quad (2)$$

Where t_{ij}^m is the reported travel time in minutes and c_{ij}^m is reported monetary cost between i and j by transport mode m in Peruvian New Soles (PNS); VOT is the estimated average value of time for commuting trips in PNS per minute by socio-economic strata (JICA, 2012). Monetary cost, c_{ij}^m , is divided by the value of time. The accessibility impedance for mode m between each origin destination pair can be expressed as the ratio of the total number of work trips between zones i and j by mode m to the total jobs in zone j as a function of generalized travel costs:

$$A_{ij}^m / O_j = e^{-(\beta_i^m \cdot C_{ij}^m)} \quad (3):$$

We estimate the β_{im} parameters for the accessibility measure, equation (1) for each year (before and after the BRT is implemented) in the treatment and control areas by regressing the log of accessibility impedance as expressed by the left-hand side of equation (3), for work trips using public transit (see Bocarejo et al., 2016) on generalized travel costs:

$$\text{Log}(A_{ij}^m / O_j) = \beta_0 - \beta_i^m \cdot (t_{ij}^m + c_{ij}^m / VOT) + e_{ij} \quad (4)$$

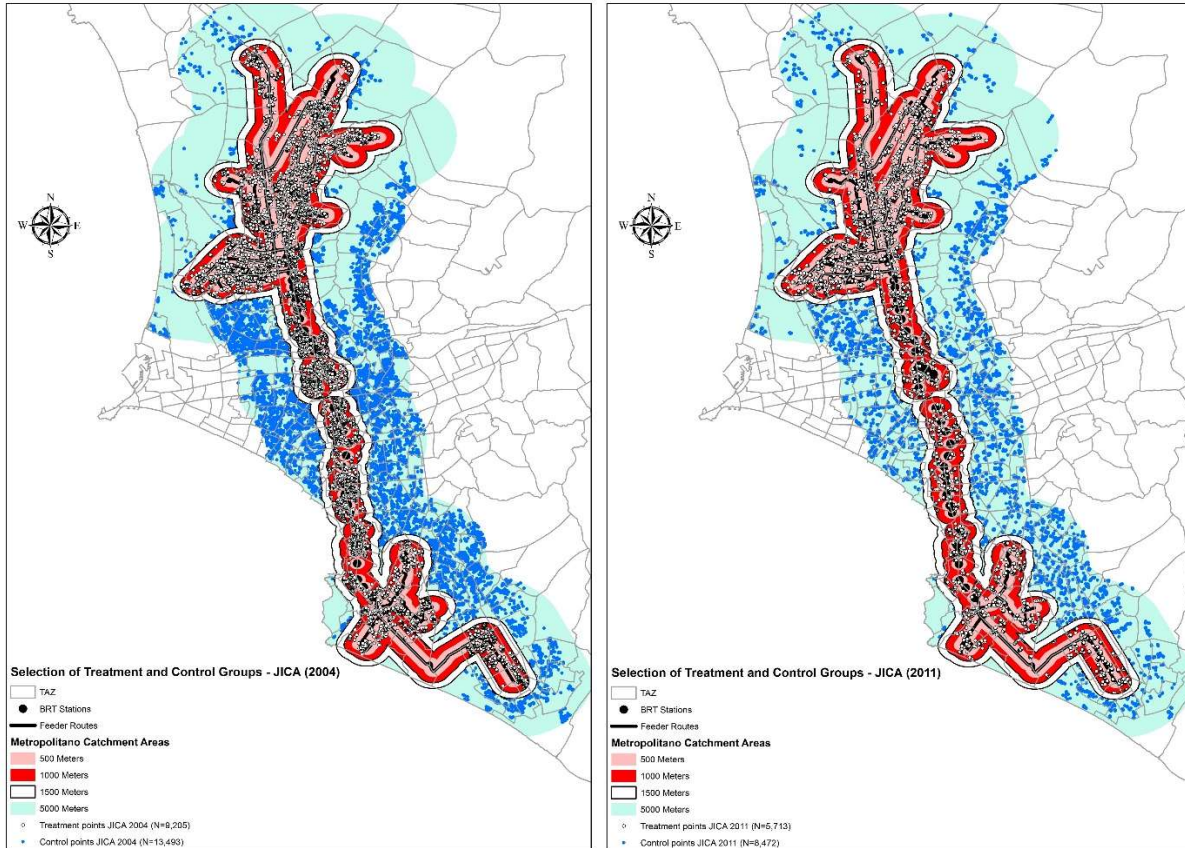
Employment opportunities (O_j) in each traffic analysis zone are held constant (in 2008) to control for potential changes in the job market in Lima and the accessibility index is divided by population of the origin zone to compare the relative difference in accessibility between different zones of the city or specific social groups.¹⁰ Only data on trips for which there is information before and after implementation of the system are used. Differences in estimates are compared among lower and higher socio-economic groups before and after the system's implementation.

Treatment areas include all data points for the Japan International Cooperation Agency (JICA) databases located between 0 and 1,000 meters from the Metropolitan trunk stations or feeder lines. We assign to the control areas all data points in the travel survey (JICA) databases that fall between 1,500 and 5,000 meters from the BRT (Figure 2). Low Socioeconomic status (SES) areas in the data source are identified by cross-referencing the geo-referenced data of the travel

¹⁰ Normalized results provide better grounds for comparison as even comparatively large absolute numbers of potentially accessible opportunities in relation to the rest of the city may be lower than the actual demand in such zone for activities such as working and studying, which can be an indicator of accessibility deficits.

survey with the shapefile of socioeconomic strata by census block from INEI. Low-SES are those households that fall within a census block with a stratum of D or E.

Figure 3 – Selection of treatment and control areas



Source: This study using JICA, 2007 OD survey data and Protransporte, 2015.

The estimates of the impedance parameters are applied to the travel costs in the same origin-destination pairs for work trips by public transit in the JICA databases for 2004 and 2012 for treatment and control group.¹¹ Because of differences in the sample size for the JICA survey in both years, the number of common origin-destination pairs available for the accessibility estimations is reduced in comparison with the original sample used for the OLS regression used

¹¹ The impedance parameters for treatment and control groups differ by 4%, showing a marginally higher negative effect of changes in the generalized cost of travel in the control group.¹¹ This is coherent with previous studies that suggest better-off areas tend to have a lower marginal response to changes in travel costs, either due to higher purchasing power or to closer proximity to job centers (Bocarejo and Oviedo, 2012; Bocarejo et al., 2014; Guzman et al., 2016).

to estimate baseline accessibility parameters. The effective sample of O-D pairs for the analysis was 6,585 O-D pairs for the treatment group and 3,257 O-D pairs for the control group in both samples of 2004 and 2012. Sample sizes are considerably reduced when segmenting by feeder and trunk catchment areas, rendering the samples sizes not sufficient for a reliable regression, particularly in the control group. For treatment, the trunk and feeder samples are 4,610 and 1,976 O-D pairs respectively, while for the control group samples are 2,606 and 651 O-D pairs for trunk and feeder areas, respectively.

Recall that the accessibility index is an exponential combination of travel costs and system demand, and therefore cannot be scaled up linearly to project changes for a doubling of ridership. However, we estimate a scenario where public transport trips between origin-destination pairs served by Metropolitano in the database, with the assumption that riders within the area of influence of the system choose the BRT over other forms of public transport was examined.

More specially, to isolate the effects of the Metropolitano on travel conditions, we carried out an additional analysis comparing only the O-D pairs in 2004 with those with trips involving Metropolitano in 2012. This comparison leads to an analysis of travel conditions to the same destinations, allowing us to compare access characteristics between BRT users and non-users to the same opportunities. The number of common origin-destination pairs available for the accessibility estimations in the Metropolitano-only scenario is reduced to 224 O-D pairs for the treatment group and 154 O-D pairs for the control group. Travel costs and times in Metropolitano between origins and destinations were replaced in trips covering the same pairs by other forms of public transport. For instance, travel costs of trips in the treatment and control groups closer to the feeder cones will incorporate the additional resources and time required to transfer from feeder to trunk services.

5. Results

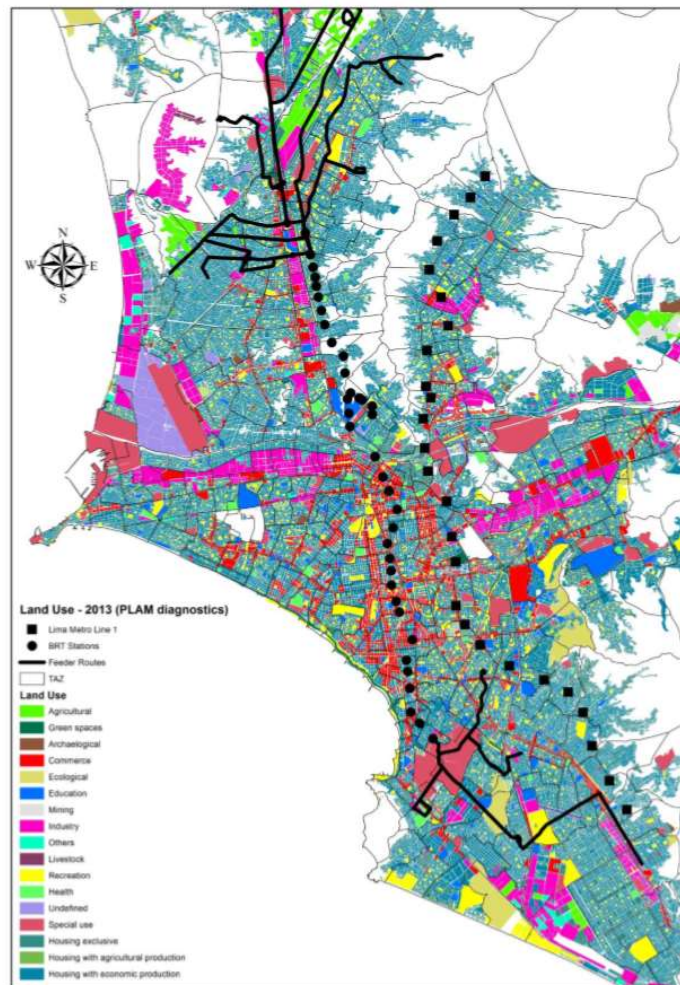
5.1 Spatial Analysis of Land use and Employment

In Lima, most land use parcels combine two or more uses, with 43% of the surface area of the city being occupied by developments providing both housing and some type of economic or agricultural production. Apartment buildings with commercial spaces on the lower floors and housing units with dedicated spaces for the operation of small firms in different sectors of the economy are a common sight throughout the city. This share of housing with economic production adds to nearly 6% of housing land having plots for urban agriculture. Such uses of land are defined

in this study as *mixed housing*. By contrast, land dedicated exclusively to housing accounts only for 18% of Lima's total surface area.

Commercial activities are concentrated in the city center and along the two main lines of mass transit, the Metropolitano and Line 1 of Lima's metro (Figure 4). The share of Lima's total surface land devoted to commercial use is comparatively small (6% of the total land area in the city), which restricts supply of commercial spaces to specific areas in the city, often those better served by transport infrastructure. Additionally, seven percent of the city's surface land area is used for industrial purposes exclusively, which concentrates in the north-east and some pockets of land in the south. Most industrial land, particularly in the east-west corridor at the center of the city (Figure 4) is not served by formal mass transit infrastructure. This may limit access to industrial employment for transit-dependent populations in the city. In contrast, commercial activities, which are concentrated in the central axis of the city, that crosses Lima from north to south, have a better comparative coverage of the current mass transit systems in operation.

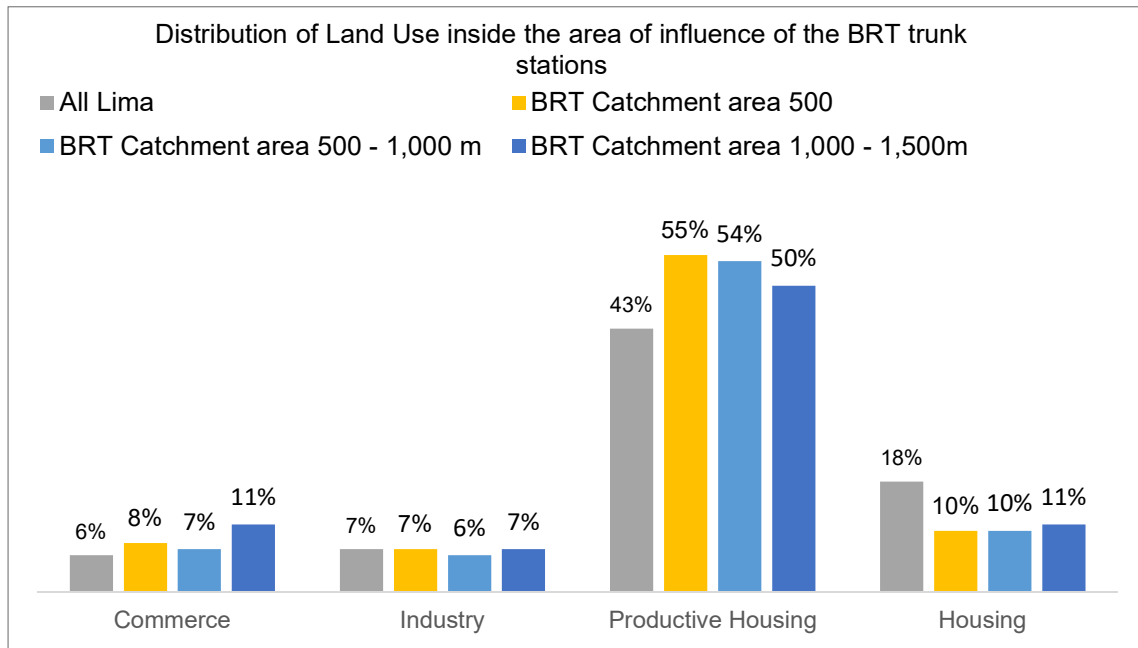
Figure 4 – Land uses in Lima, 2013



Source: This study using PLAM 2035 diagnostics.

Land use within the BRT catchment areas is predominately dedicated to mixed-use housing and commercial uses, with a relatively higher proportion of these uses in comparison with land use the rest of the city. Fifty-five percent of land area within 500 m from the BRT stations is mixed housing in comparison to 43% for the remainder of the city (Figure 5). In contrast, the BRT station areas have a lower percentage of the surface land area dedicated exclusively to housing (10% within the 1,500 m catchment area), in comparison to just 18% of total surface land of the remainder of the city. Commercial land use is also more concentrated around the BRT, with 11% of land within 500 m of the stations are commercial in comparison with just 6% in the rest of the city.

Figure 5 - Distribution of main land uses within catchment area of mass transit in Lima, 2013



Source: This study using PLAM 2035 diagnostics.

Table 1 compares the ratio of distribution of land use within the catchment areas of the of the Metropolitano with the distribution of land uses in Lima for the trunk and feeder systems. From a land use perspective, the design of the BRT system appears to coincide with higher concentrations of productive land in the city, improving the connectivity of major developments with areas of higher concentration of housing. Relative to the rest of the city, commercial land use is concentrated within the catchment areas of the Metropolitano trunk, but not along the feeder system. Fifty-five percent of the total surface land area devoted to commercial use in Lima concentrates within 1,500 m from the Metropolitano system (18.5% within 500 m). Moreover, the system covers over 44% of the productive housing surface area in the city, while its coverage of housing land is higher within the inner buffer than in the range above 1,000 m. Mixed housing is consistently highly concentrated throughout the Metropolitano network in comparison with other relevant land uses and to the rest of the city. Finally, thirty-three percent of Lima’s industrial surface land area is within 1,500 m of the BRT and is mostly concentrated in the southern feeder area. Thus, overall, the distribution of land use around the BRT system’s trunk stations provides access to retail and service opportunities, particularly those associated with small businesses in mixed housing, and the system provides connection to industrial employment opportunities along the south feeder systems.

Table 1 – Ratio of distribution of land use inside the area of influence of the Metropolitano vs. Distribution of land use in Lima

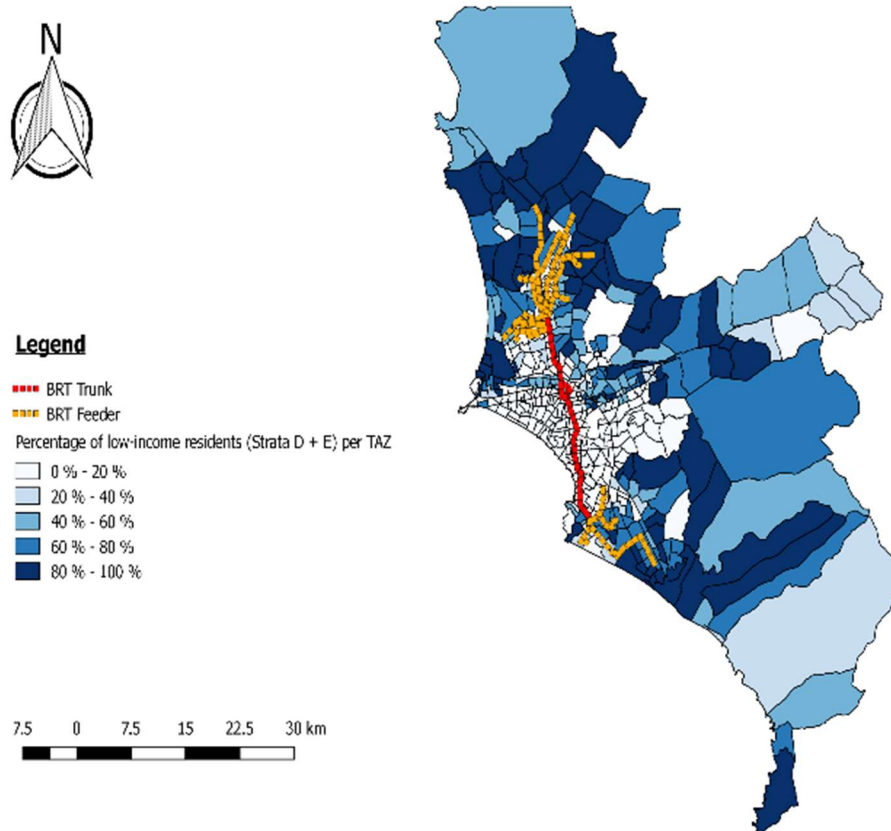
Land Use	BRT stations			BRT North Feeder			BRT South Feeder		
	0-5km	500m-1km	1km-1.5km	0-5km	500m-1km	1km-1.5km	0-5km	500m-1km	1km-1.5km
Commerce	1.40	1.32	2.04	0.89	0.22	0.32	0.52	0.39	0.56
Industry	0.96	0.90	1.02	0.93	0.70	0.56	1.46	1.55	1.70
Mixed Housing	1.30	1.26	1.17	1.44	1.48	1.20	1.26	1.31	1.30
Housing	0.54	0.56	0.58	0.50	0.63	0.58	0.51	0.4	0.38

Source: This study using INEI's Economic Census (2008).

This is relevant for the analysis of access to employment as it points to the concentration of economic opportunities in proximity to the system. We explore further the effects of this concentration of land by examining employment information and the accessibility analysis that follows.

5.2 Employment Access

Figure 6 – Percentage of low-income residents per Transport Analysis Zone (TAZ)



Source: This study using data from JICA and INEI (2007).

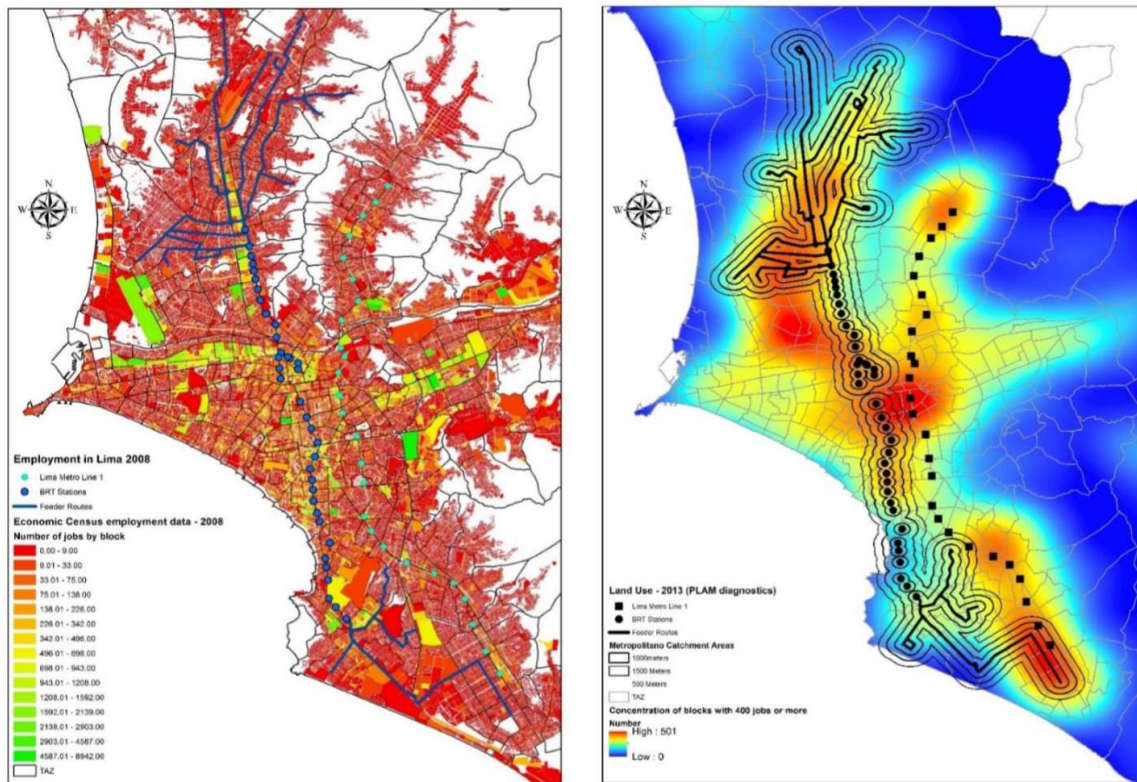
Figure 6 shows that most of the low-income population in the area of influence of the BRT are only covered by its feeder lines, while a large share of poorer neighborhoods farther from the city center has no access to the system (Figure 6).¹² Also notable is a consistent increase in poorer residents in areas far from concentrations of productive land (Figure 4).

Figure 7 shows the distribution of employment in Lima and a heatmap of large job suppliers (400 jobs or more) throughout the city. Most of the job supply in the city is provided by small

¹² The population of Lima is divided into five strata by socioeconomic status as estimated by the Peruvian Association of Enterprises Market Investigation (also known by its Spanish acronym, APEIM), using household survey data from Peruvian National Household Survey (also known by its Spanish acronym ENAHO). In 2013, 7.6% of the population was classified as Stratum E (roughly half the share in 2007 of 16.4%), 30.3% Stratum D (compared with 34% in 2007), 38.4% Stratum C, 18.5% Stratum B, and 5.2% Stratum A. Some of the highest concentrations of population from Strata D and E are in the districts of Puente Piedra, Comas, and Carabaylo in the north; Villa El Salvador, Villa María del Triunfo, Lurín, and Pachacamac in the south; Ate and Lurigancho to the east; and Callao to the west. See [http://www.apecim.com.pe/wp-content/themes/apecim/docs/nse/APEIM-NSE-2013.pdf](http://www.apeim.com.pe/wp-content/themes/apecim/docs/nse/APEIM-NSE-2013.pdf)

businesses¹³ distributed throughout the city, with larger employers (400 jobs or more) located in areas with high concentrations of industrial land use and pockets of large businesses along some of the main transportation links in the city (Figure 7). Over half (54%) of jobs are concentrated in middle to high-income areas, or middle to upper socioeconomic status (strata B and C), while 19% are in areas characterized as lower income (stratum D), 25% in predominately extremely poor areas (stratum E), and 2% in wealthier areas (stratum A).

Figure 7 – Distribution of employment in Lima & heatmap of businesses with higher job supply - Lima, 2008



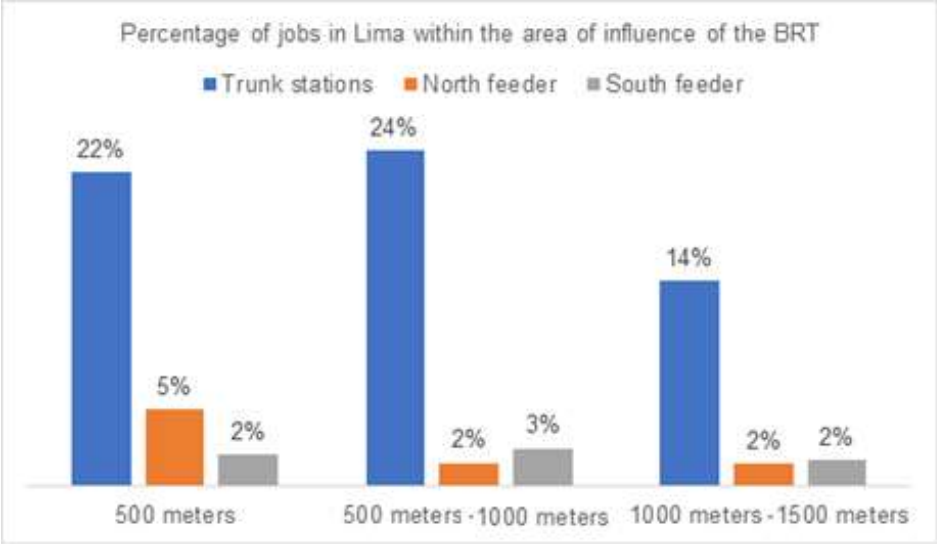
Source: This study using census data (INEI, 2008).

The heatmap analysis of employment distribution in the city is consistent with the analysis of land use in the city discussed above (See Figure 7 - right). The 1,500 m catchment area around the Metropolitan network, which covers approximately 35 percent of total land surface area in Lima, encompasses many of Lima’s employment hotspots, providing connectivity to nearly 80% of formal jobs in the INEI’s economic census (2008) within 1,500 m of its trunk stations and feeder routes. The trunk-line stations alone cover 60% of employment within the buffer (see Figure 8). The close links between coverage of the BRT system and the main employment clusters in Lima

¹³ This is consistent with a land use pattern dominated by mixed housing.

point towards potential positive effects in access to employment for public transit users living near the system. This may also lead to reinforce already consolidated high-value areas in the city, contributing to centralization of economic opportunities and increase in land values around the BRT stations. This analysis of the BRT's impact on access to jobs has two limitations. As information is available only for the year 2008, a detailed analysis of the evolution of the job market throughout Lima was not possible for this paper. In addition, data on information that would enable the analysis of the skills and training requirements for formal jobs within the system's catchment and potential (mis-) matches with skills and training of people in strata D and E was not available.

Figure 8 – Employment concentration in BRT catchment areas



Source: This study using census data (INEI, 2008)

5.3 Accessibility Analysis Results

Table 2 shows summary statistics of work-related trips in public transit in 2004, six years prior to the opening of the BRT line. Work trips within walking distance to the BRT (or the treatment area) are characterized by lower average travel times but higher monetary costs in comparison with both the city's average and that of trips originating from the control areas, implying increased access (in terms of travel times) to employment in the treatment group before implementation of the Metropolitano. However, higher monetary costs may indicate an increased willingness to trade-off economic costs for shorter travel times (i.e. higher value of time) and be related to the clustering of more formal jobs close to major transportation infrastructure.

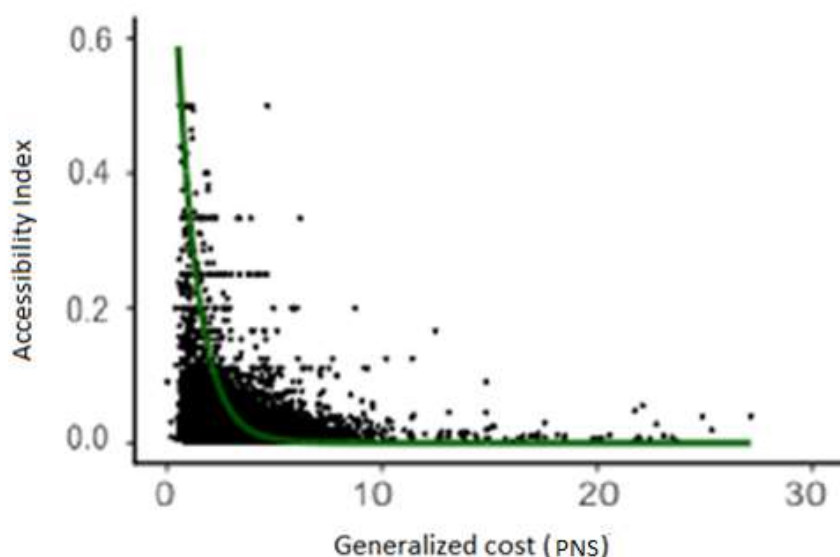
Table 2 – Average travel costs and sample sizes for work trips in public transit - Lima, 2004

Sample	Mean Travel time (minutes)	SD Travel time (minutes)	Mean generalized travel cost (PNS*)	SD generalized travel cost (PNS)	N (Origin- Destination pairs)
City*	43.1	22.8	2.7	2.1	3,358
Control	42.1	21.3	2.7	2.5	1,447
Treatment	43.9	23.9	2.6	1.6	1,911

Source: This study using JICA, 2004.

Notes: Calculations include all observations from the control group, treatment group and others. *Peruvian Nuevo Sol (PNS).

Figure 9 - Fitted line: Accessibility index (ratio of jobs accessed to jobs available) as a function of generalized travel costs (full sample model) – Lima, 2004



Source: This study using JICA, 2004.

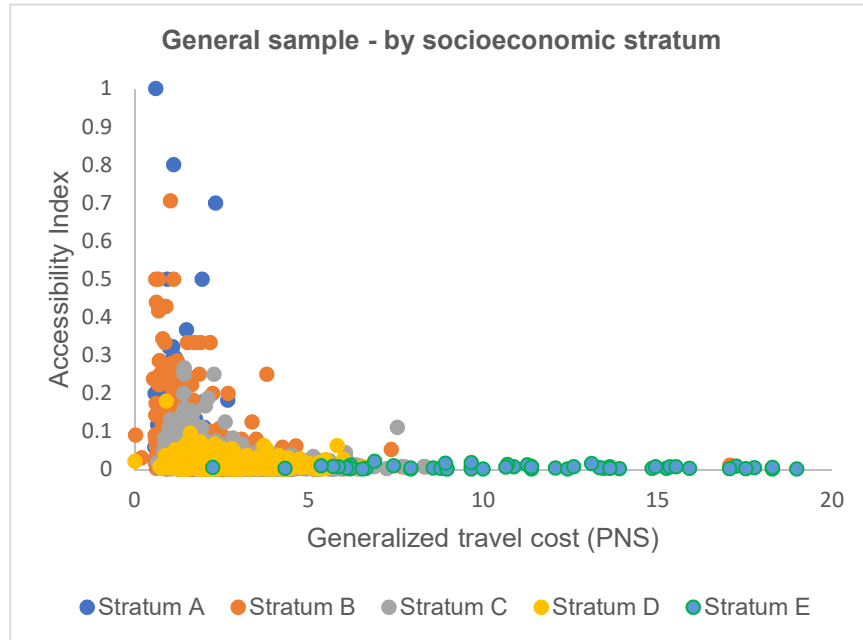
The scatter plot of estimated accessibility index and generalized travel costs for each origin-destination pair in the baseline year (2004) reveals a curve that is consistent with distance decay functions found in previous studies on the subject (See Bocarejo & Oviedo, 2012; van Wee et al., 2002) (Figure 9). We next regress the ratio of job-related trips to total jobs on the generalized travel cost for work trips by public transit in the baseline year as discussed above. The estimate of the parameter (-1.025) on general travel cost is statistically significant at the 1% level (Figure 9 and Table 5 ($t = -183.8$)).¹⁹ Moreover, the model estimate has high explanatory power ($R^2 = 0.72$).

Baseline information for Lima is also used to identify general accessibility patterns by socioeconomic stratum before the project. Strata D and E had higher generalized costs and lower accessibility indices, while mid strata such as C had lower travel costs and comparatively higher accessibility indices (Figure 10). Conversely, data points with higher values of accessibility correspond primarily to more well-off socio-economic groups, strata A and B. These observed accessibility indices show a consistent tendency with past studies- that lower income groups tend

¹⁹ This initial estimation, although not used for the accessibility analysis between groups of analysis, is a relevant first step in determining the appropriateness of the distance decay function for representing Lima's conditions.

to have higher travel expenditure and lower accessibility indices (see Bocarejo & Oviedo, 2012; Bocarejo et al., 2014; Falavigna & Hernandez, 2016).

Figure 10 - Fitted line: Accessibility index (ratio of jobs accessed to jobs available) as a function of generalized travel costs by socioeconomic stratum (full sample model) – Lima, 2004

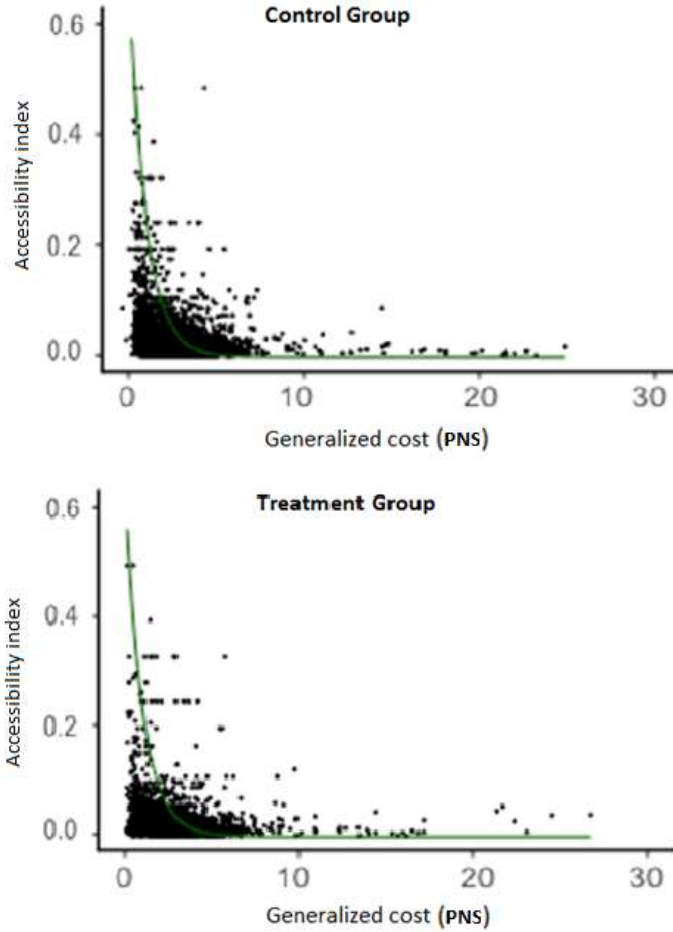


Source: This study using JICA, 2005.

Comparisons of the estimates of accessibility curves by treatment and control groups show a steeper curve in the control group and thus more rapid changes in accessibility with smaller changes in travel costs (Figure 11). The two groups show a similar distribution of travel costs and observed ratios of jobs accessed to jobs offered at different destination zones, with slightly higher mean generalized travel costs in the treatment group (8% higher) and no significantly different accessibility indices.²⁰

²⁰ The general trends observable in both groups are consistent with the patterns observed in the aggregated sample and the literature.

Figure 11. Observed accessibility index (ratio of jobs accessed to jobs available) as a function of generalized travel costs by groups of interest – Lima, 2004



Source: This study using JICA, 2004.

Table 3. Estimation results for the accessibility index impedance parameter (generalized travel cost) – samples by groups of interest model (2004)

	β_i^m	Standard Error	t Value	N	Adjusted R-Squared
Accessibility index (full sample)	-1.025	0.006	-184	13,250	0.720
Accessibility index (control)	-1.014	0.009	-120	3,257	0.684
Accessibility index (treatment)	-0.979	0.010	-92	6,568	0.720

Source: This study using JICA, 2004.

Note: The accessibility index is the ratio of jobs accessed to jobs available.

The impedance parameters for treatment and control groups differ by 4%, showing a marginally higher negative effect of changes in the generalized cost of travel in the control group. This is coherent with previous studies that suggest better-off areas tend to have a lower marginal response to changes in travel costs, either due to higher purchasing power or to closer proximity to job centers (Bocarejo and Oviedo, 2012; Bocarejo et al., 2014; Guzman et al., 2017).

Tables 4 to 5 show tests of differences in mean travel costs and time between income levels and year for the control and treatment groups for work trips. Work trips via public transit in the treatment area in the year 2004, prior to the BRT line opening, were slightly shorter but more expensive in comparison with those originating from the control area. The share of users of the Metropolitano in the sample is comparatively low compared with other public transit alternatives in the year of the survey. According to the JICA survey for 2012 the BRT accounted only for 3.6% of trips in public transport and 2.7% of all trips in the city, however, since the treatment and control groups are much closer to the area of influence of the BRT, the percentage of trips in Metropolitano is comparatively higher in the study sample. In the treatment group, out of the total number of work trips by public transit, over 9% involve the Metropolitano in at least one stage of the trip, while in the control group only 5% of work trips involve the BRT in combination with other forms of public transport.

Increases in travel costs and times are observed in both the treatment and control areas. Most of the increase is related to increases in the economic costs between 2004 and 2012. Travel times increased slightly, but insignificantly for lower income groups, and more markedly amongst the higher income group. The marginal changes in reported travel times in the JICA survey of 2012 compared to those in 2004 suggest there have not been significant changes in travel conditions by public transport (Table 5). In addition, statistically significant differences are only detectable amongst the higher-income group. Increases in traffic and other network-related variables not measured in this study may have dampened gains in travel time associated with the introduction of the Metropolitano. This is likely compounded by the small percentage of the demand being served by the system in 2012, as mentioned above.

Table 4. Differences in mean travel times (minutes) between socioeconomic groups for treatment and control

	2004	2012	N	Difference	%	Confidence Interval
<i>Treatment</i>						
High SES	43.9	46.5	1,245	2.6	5.90%	(-0.15; 5.36)
Low SES	48.5	50	666	1.5	3.10%	(-3.21; 3.45)
<i>Control</i>						
High SES	44	47.4	887	3.4	7.60%	(1.53; 5.17)
Low SES	47.8	47.9	739	0.1	0.20%	(-3.21; -3.45)

Source: This study using JICA, 2004 and 2012.

Table 5. Differences in mean monetary costs (2004 PNS) of travel by socioeconomic groups and treatment and control

	2004	2012	N	Difference	%	Confidence Interval	P-value
<i>Treatment</i>							
High SES	2.59	3.30	1,245	0.71	27.4%	(0.53; 0.89)	0.00
Low SES	3.12	3.55	666	0.43	13.9%	(0.03; 0.84)	0.03
<i>Control</i>							
High SES	2.86	3.11	887	0.25	8.8%	(0.57; 0.81)	0.00
Low SES	2.86	3.60	739	0.74	26.2%	(0.28; 1.21)	0.00

Source: This study using JICA 2004 and 2012.

After the introduction of the Metropolitano, the largest percentage increase in monetary costs amongst those in the treatment area were incurred by higher income public transport users. Reported costs increased by 0.71 PNS, or 27% in 2012 relative to 2004 for this group. In comparison, higher income transit users in the control group saw a rise of 8% in monetary expenditures. In contrast, monetary expenditures for work trips in public transit for the low-income treatment groups increased, but considerably less in percentage terms, than among those in the control area, or by 14%, while low-income public transit users in the control areas experienced much larger percentage increases in travel costs.²¹

This could be attributable to the fare structure of the Metropolitano compared to other forms of public transport in Lima. The Metropolitano has a higher fare for the trunk services than other forms of public transport, although the integrated fare when using the feeder routes in combination with the trunk, is comparatively cheaper than two or more transfers in traditional public transit. In addition, the introduction of the system led to some the restructuring of some public transport

²¹ The costs presented in Table 5 are those reported by survey respondents in the JICA database for the two years of analysis.

routes, which may have led some lower-income users of traditional public transport to require more transfers for longer trips, hence increasing the travel costs, particularly for those in the control areas where public transit services charge by trip distance.²²

Table 6. Differences in mean accessibility indices by socioeconomic and treatment and control groups

	2004	2012	N	Difference	%	Confidence Interval	P-value
<u>Treatment</u>							
High SES	0.14	0.11	1,245	-0.03	-22%	(-0.05; -0.01)	0.00
Low SES	0.09	0.07	666	-0.02	-19%	(-0.04; 0.00)	0.08
<u>Control</u>							
High SES	0.14	0.10	887	-0.04	-29%	(-0.05; -0.03)	0.00
Low SES	0.09	0.08	739	-0.01	-15%	(-0.03; -0.002)	0.09
<u>Difference in Difference</u>							
High SES				0.01	7.0%	(-0.06; 0.02)	0.20
Low SES				-0.01	-11%	(-0.07; 0.01)	0.26

Source: This study using data from JICA, 2004 and 2012.

As shown in Table 6, between 2004 to 2012, baseline accessibility indices are highly similar in the treatment and control groups. The accessibility indices decreased in both the treatment and control areas and for both SES groups over the study period. The high-SES subgroup experienced a larger and statistically significant decrease in accessibility overall compared to lower SES populations, however, it declined substantially less, 22 percent, in the treatment area than in the control, where it declined by 29 percent. Overall, the BRT appears to have counteracted declines in accessibility among higher SES transit users living within 1 km of the system.

The combined effect of both longer and more expensive work trips in 2012 in comparison with the baseline leads to a decrease in potential accessibility to jobs in both the treatment and control areas and for both SES groups. The changes in accessibility can be attributed primarily to increases in monetary travel costs; travel time in the two periods of analysis increased only slightly, while monetary travel costs increased more dramatically (see Table 6). The t-tests of differences in mean accessibility indices show that higher SES transit users in the control group experience the highest accessibility losses (29%); in comparison, accessibility declined by 22 percent for the same SES group in the treatment group. In contrast, in the lower SES groups in

²² However, the restructuring of the competing informal operators was delayed for political reasons and took place gradually over time and therefore, impacts on transfers may not have been significant in 2012.

the control area experience the lowest loss of accessibility of 15%, while in the treatment area, accessibility declined even more significantly, by 19%.

The analysis of differences in differences within SES sub-groups suggests a positive effect of the Metropolitano in potential accessibility in the higher SES group. Relative to the control group accessibility increased in the 1 km boundary area of the BRT by 0.01, a 7% increase relative to the treatment baseline accessibility index. In other words, while accessibility declined, it declined seven percent less so in the area of the BRT area of influence. In contrast, in the lower-SES group, the double difference is -0.01, an 11% decrease relative to the baseline accessibility index (0.09).²³ However, as shown in Table 6, these results are not statistically significant.

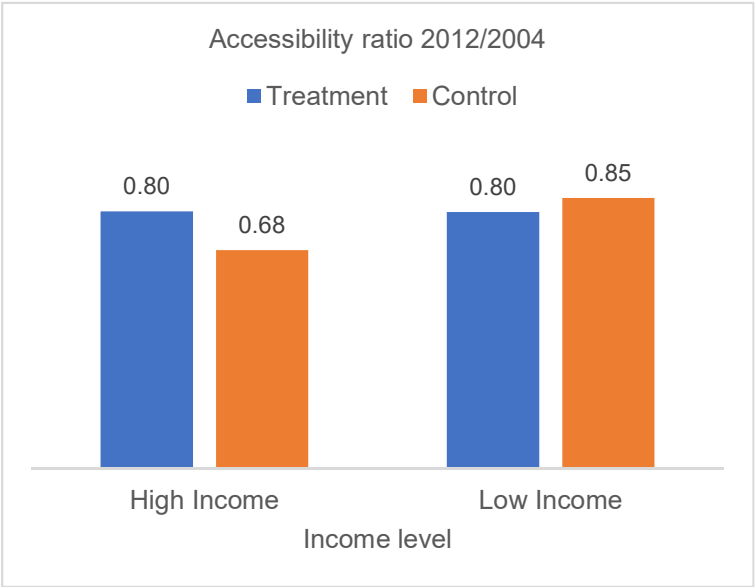
Examining the changes in travel time in the treatment versus control groups among lower SES commuters, the results appear to be driven by larger increases in travel times in the treatment area versus the control areas. Increases in travel times for the poor within the treatment area could be related to lower BRT ridership among the poor as found in a prior study (Scholl, et al, 2015). Longer travel times could also be related to the restructuring of traditional bus operators in the area of influence of the system. Such restructuring of routes of the traditional transit operators could imply longer travel times for the same trips. In addition, since the tariff was not yet integrated at the time of the survey, it would be more expensive for a lower SES rider coming from the periphery to a feeder and trunk trip, relative to a trip on a traditional public transit mode, potentially discouraging low SES riders from using the system and a continued reliance on competing modes. Moreover, as the coverage of the system has higher coverage for the Transport Analysis Zones -TAZ- characterized as primarily middle class (strata C) and above, it provides connectivity to employment hotspots, and has higher tariffs that can be better-absorbed by populations with higher purchasing power.

Despite overall increases in travel expenditure, the results imply better accessibility for higher SES TAZs in the treatment zones than for those of poorer strata in the same group, calling into question the contribution of the Metropolitano to the mobility and inclusion of the poor at the time of the survey. Although these results should be taken with caution as at the time of the survey the system had not yet reached its projected ridership levels, had fewer feeders and trunkline buses in operation than planned, and had a tariff structure that made the feeder system considerably more expensive, than it is today.

²³ It should be noted that statistical power is higher for the higher income sub-groups, as they represent a larger percentage of the sample (81% in treatment and 85% in control).

The results above can also be expressed in terms of the total number of jobs accessed in the baseline year and in 2012 by multiplying accessibility indices by the supply of job opportunities at each destination zone, which provide a clearer depiction of the distribution of gains and losses in travel costs in relation to the concentration of employment in each zone. Figure 12 shows the ratio of accessed jobs in 2012 to accessed jobs in 2004 disaggregated by SES levels. While in the treatment group accessibility after the introduction of the Metropolitano is about 80% of the jobs accessed in the baseline year, larger losses are experienced in the high-SES portion of the control group. The lower-SES group in the control group, however, shows lower losses in relation to the baseline scenario. The treatment group accessed nearly 811,000 jobs in 2004, which would be reduced to 651,000 jobs under the travel conditions in 2012 (a ratio of 0.80 jobs in 2012 compared to 2004). In the control group, which has a much larger sample of origins and destinations, this number is reduced from 1.83 million jobs potentially accessed in the baseline scenario to 1.28 million jobs approximately, 0.7 times the original value.

Figure 12. Accessibility (accessed jobs) ratios 2012/2004 by control and treatment groups and socioeconomic categories



Source: This study using OD survey data from JICA 2004 and 2012.

The results suggest changes in travel conditions for the groups in the area of influence of the Metropolitano did not have a positive effect on accessibility compared to the baseline year, at least in 2012. These results are influenced not only by the changes in travel attributes, but the elasticities of different SES groups to changes in both time and cost. The use of generalized travel costs also reflects the value of time for different sociodemographic groups, which influences

accessibility. Both the aggregated and disaggregated accessibility estimations reflect variations in socioeconomic characteristics and therefore in the value of time. In general, households living in areas closer to the trunk line of the Metropolitano near the city center tend to be of higher socioeconomic stratum. Higher SES travelers tend to have less tolerance for increased travel time and higher willingness to pay economically to reduce travel duration, compared to lower-SES groups. And therefore, are usually more likely to benefit more directly from investments in mass transit systems, where speed and efficiency are relevant design features, all else equal. However, these benefits seem to be outweighed by the increase in costs and travel times associated with the rise in congestion and waiting times for other modes.

These findings can also be partly explained by a limited share of the transport demand under study served by the BRT system. As ridership was less than half of what was projected and half the ridership in 2016 (over 600,000 per day), in the initial stages of the system's operation, the Metropolitano seems to have played a palliative rather than transformative role in reducing the travel costs to work of transit users within its area of influence. However, it is important to note that the 2012 survey period may be too early to detect the full impacts.²⁴

Tables 7 and 8 show the differences in mean travel time and cost between SES groups for the Metropolitano-only scenario discussed in the methodology section. When isolating the effects of the Metropolitano for the same destinations, a meaningful reduction in travel time for the treatment group can be identified both in the high and low-SES group with high statistical confidence (1% level). This supports the hypothesis that the Metropolitano's benefits in terms of speed are overshadowed by its small participation in transit demand for work trips at the time of the travel survey, only one year after implementation of the system. However, the data for this analysis is also concentrated in common destinations for the trips that involve the system, which are mainly distributed in or around its area of influence. Results in Table 7 suggest therefore that the Metropolitano has the potential to provide travel time benefits for the destinations it covers in comparison with previous transit alternatives in the baseline. The examination of differences in mean travel costs does not show statistically significant differences in either control or treatment, despite observable changes suggesting a slight increase in travel costs for the higher SES subgroups.

²⁴ Metropolitano ridership was 404,202 validations a day in mid-2012, two thirds of the expected ridership that was projected and is observed in 2016.

Table 7. Differences in mean travel times (minutes) between socioeconomic groups for treatment and control – Metropolitan-only scenario

	2004	2012	Difference	Difference (%)	Confidence Interval	P-value
Treatment						
High SES	54.4	43.6	-10.8	-19.90%	(-13.85; -0.06)	0.00***
Low SES	44.8	34.4	-10.4	-23.20%	(-14.81; 1.88)	0.00***
Control						
High SES	58.7	59.8	1.1	1.80%	(-3.83; 0.27)	0.49
Low SES	50.1	48.3	-1.8	-3.60%	(-4.91; 0.98)	0.21

Source: This study using OD survey data from JICA 2004 and 2012.

The differences in mean accessibility indices in the scenario of Metropolitan-only travel suggests changes in the ‘reachability’ of destinations analyzed are positive for the treatment group and have statistical significance at 5% confidence for the low-SES sub-group. Although the mean accessibility index increases in the higher-SES group, it is not possible to argue with statistical confidence that the change between the two years is significant. The Metropolitan improves travel time considerably for longer trips, which tend to be made more often by poorer populations farther from the city center.

Table 8. Differences in mean travel costs (2004 PNS) between socioeconomic groups for treatment and control – Metropolitan-only scenario

	2004	2012	Difference	Difference (%)	Confidence Interval	P-value
Treatment						
High SES	3.09	3.21	0.12	3.80%	(-0.11 - 0.41)	0.16
Low SES	3.25	3.24	-0.01	-0.30%	(-0.13 - 0.04)	0.46
Control						
High SES	3.84	3.92	0.08	2.10%	(-0.07 - 0.36)	0.29
Low SES	4.25	4.42	0.17	3.90%	(-0.04 - 0.59)	0.12

Source: This study using OD survey data from JICA 2004 and 2012.

The accessibility indices in this scenario suggest that for lower-SES travelers, whose trips typically required more transfers to reach some areas with high supply of jobs prior the implementation of the system, the conditions for access have improved. This is of course restricted to destinations that the system reaches, which are only relevant for about one-third of the treatment group sample of public transit destinations. Moreover, the lower-SES group represents only 28% of the work trips involving the Metropolitan, which points to the very limited scale of representativeness of the system’s benefits in the travel survey and its low levels of use a year after implementation.

A simple difference-in-difference was applied to the data as the sample sizes in the treatment and control in the Metropolitan-only scenario do not allow for sufficient statistical power for obtaining

significant results, similar to what was observed in the diff-in-diff estimations of Table 6 for the general sample.

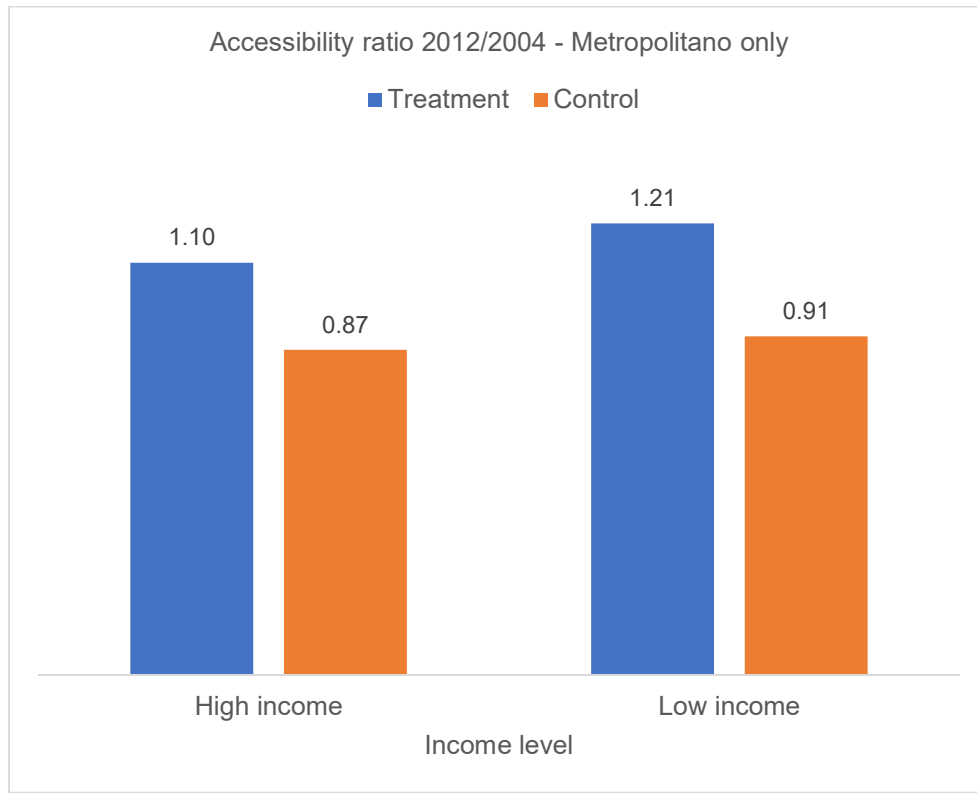
Table 9. Differences in mean accessibility indices between socioeconomic groups for treatment and control – Metropolitan only scenario

	2004	2012	Difference	%	Confidence Interval	P-value
<u>Treatment</u>						
High SES	0.07	0.08	0.01	7%	(-0.01 - 0.02)	0.19
Low SES	0.05	0.06	0.01	19%	(-0.01 - 0.03)	0.05**
<u>Control</u>						
High SES	0.08	0.06	-0.02	-22%	(-0.04 - 0.00)	0.08*
Low SES	0.08	0.06	-0.02	-24%	(-0.11 - 0.07)	0.59
Simple Difference in Difference						
High SES			0.03	43%		
Low SES			0.03	60%		

Source: This study using OD survey data from JICA 2004 and 2012.

Results of accessibility (jobs accessed) ratios 2012 to 2004 are shown in Figure 13. The number of jobs potentially accessible increase more in the low-SES treatment sub-group, although there is a marginal positive effect in the higher SES group as well. Results in Figure 13 reflect the potential accessibility gains if about one third more low-SES people could access the Metropolitan.

Figure 13. Accessibility (accessed jobs) ratios 2012/2004 by control and treatment groups and socioeconomic categories -Metropolitano only scenario



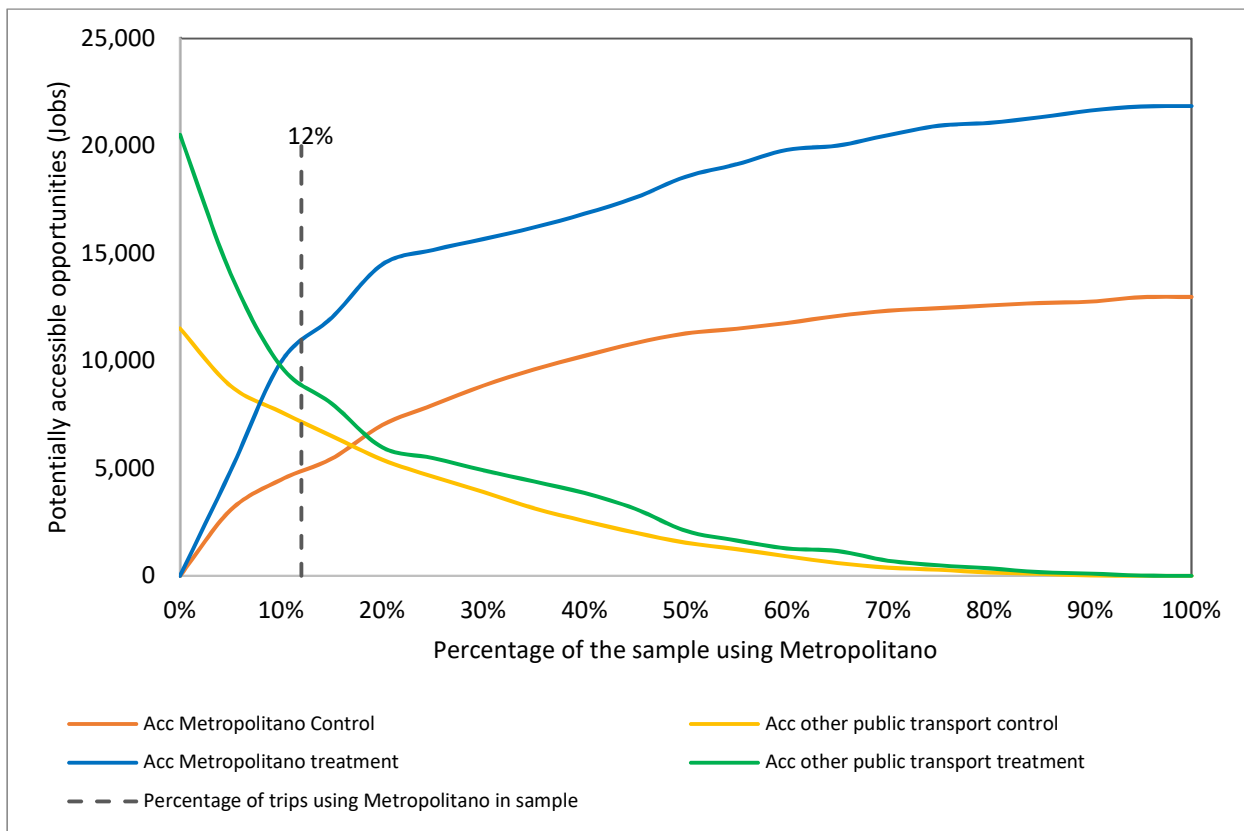
Source: This study using OD survey data from JICA 2004 and 2012.

The analysis of the Metropolitano-only scenario for the destinations served by the BRT suggest that a scaling-up of the travel conditions of the system may produce considerable accessibility gains for populations in its area of influence. Given the limited sample size for both treatment and control, we developed a sensitivity analysis of the changes in accessibility as a function of the percentage of trips to work by Metropolitano. This analysis was conducted only for origin-destination pairs where data for Metropolitano trips is available, following the same logic as in the previous scenario. The initial distribution of public transit demand in the sub-sample of destinations served by the Metropolitano reflects that 12% of the demand of all public transit trips is served by the BRT. When differentiating by control and treatment the shares of the demand served by the system are 11% and 14%, respectively. For the sensitivity analysis, travel attributes of trips between the same origin and destination by forms of public transport other than the Metropolitano are progressively replaced by the average time and cost of trips in the BRT.

Figure 14 compares the number of potentially accessible job opportunities in 2012 for different scenarios of the share of the public transit demand met by the Metropolitano. As shown below, in

the treatment group, the Metropolitano starts making a higher contribution to accessibility than other forms of public transport, which is around 11% of the share of total demand for public transit. By contrast, in the control group this happens at 20%, which may be explained by previous results. Data of travel costs and times examined earlier suggest that within its immediate area of influence, the Metropolitano provides better travel conditions to destinations with higher supply of job opportunities, increasing accessibility more rapidly than in the control area.

Figure 14. Potential accessibility for users of public transit Vs. percentage of trips in BRT, 2012 (Metropolitano only sub-sample)

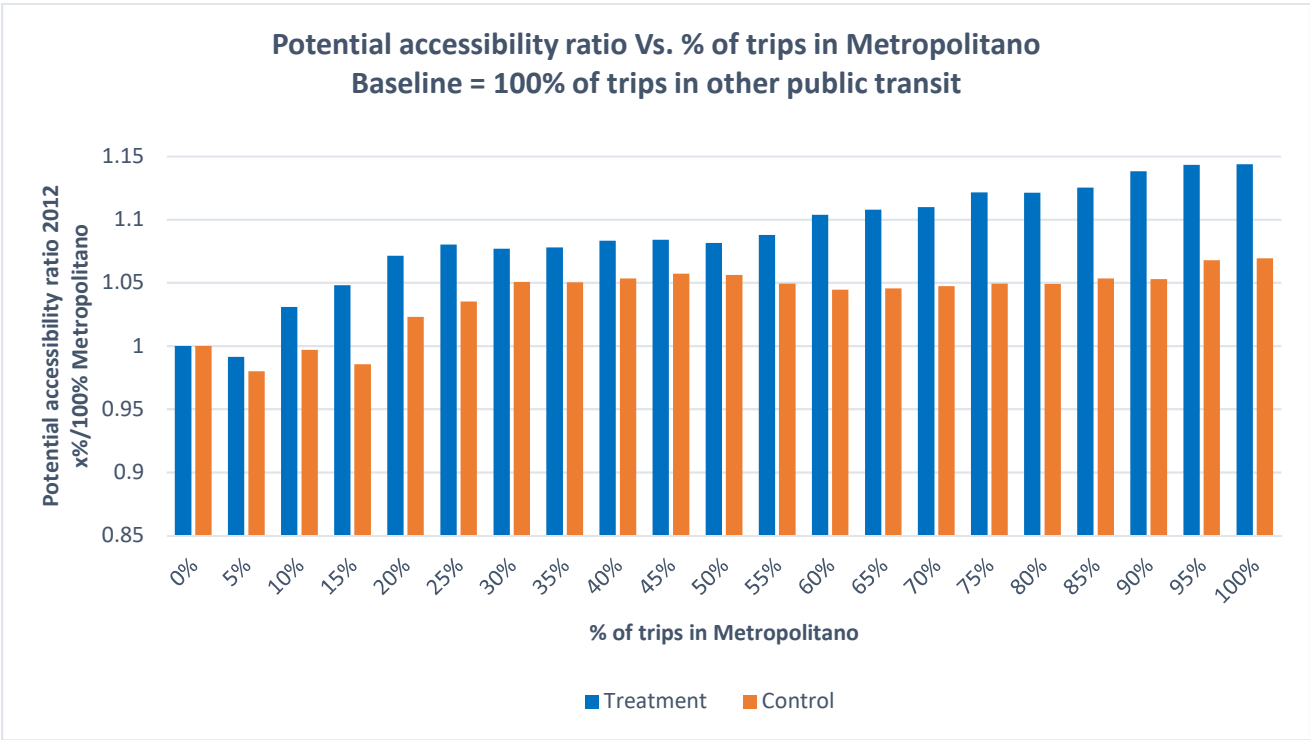


Source: This study using OD survey data from JICA 2004 and 2012.

Figure 15 shows the ratio of total accessibility in 2012 as a function of changes in the percentage of trips to work served by the Metropolitano and the total accessibility in a scenario where 100% of the trips are served by other forms of public transit. As shown below, the combined accessibility gains when 10% of the demand in the treatment area use BRT and 90% use other public transit are marginally higher than the total accessibility in a scenario where collective transit serves all the travel demand of destinations covered by the Metropolitano. In the control area, this is only achieved after replacing travel attributes of 30% the demand of other public transport with the features of the BRT. With a 60% substitution in demand, the accessibility in the treatment group

would be 10% higher than the accessibility in the baseline scenario. The additional distance to the system and more limited coverage in the control area may explain these trends as higher costs of accessing the BRT produce losses in accessibility compared with other transit alternatives. Nevertheless, considering the increase in travel costs between 2005 and 2012, and the results observed in Figure 13, even marginal gains in accessibility in this scenario have a positive effect in relation to the potential losses in the control group if all the demand used other public transit. Results reflect that despite that accessibility in the control groups is 86% of the level of accessibility in 2004 under a scenario of 100% substitution, this would still be nearly 7% higher than the accessibility if users continued traveling only by other forms of public transit. This is a relevant finding in terms of policy and planning of the system, as it supports the need to increase ridership and provide incentives for substitution of trips in traditional forms of transit for trips in the BRT, particularly for those trips directed to destinations in the area of influence of the system. However, the limitations of these benefits are circumscribed to specific areas of the city and, as shown in the employment and land-use analysis, specific types of opportunities.

**Figure 15. Potential accessibility ratio Vs. percentage of trips in BRT, 2012
(Metropolitano only sub-sample)**



Source: This study using JICA (2012) and Peruvian Economic Census Data (2008).

6. Discussion and Conclusions

Our analysis explores the underlying components of accessibility to employment related to the development of Lima's Metropolitan system from a social inclusion perspective. In relation to land use and coverage of opportunities, results suggest that the Metropolitan achieved positive results in relation to physical coverage and improvements in travel conditions within its area of influence. One of the main considerations in transport policy from a social perspective is the issue of affordability, which results suggest worsened over time, affecting particularly low-SES groups. Lack of an integrated fare policy in 2012, the post-Metropolitan year of analysis is likely to have an effect on the results as travel costs reflect the additional economic burden of full-fare transfers, reducing availability of disposable income and limiting the ability of the poor to afford travel to non-income-generating opportunities, shortening the path to social exclusion.

The layout of the Metropolitan network was planned to serve one of the highest demand corridors of the city, and as such, naturally coincides with the areas of higher concentration of formal opportunities and economically productive land uses in the city. Thus, it increases the connectivity of already high-value areas in the city. The system provides an extended coverage of the city from north to south, despite having only one trunk line, which is aligned with a significant share of formal job opportunities in the city.

While this may be beneficial for those with access to the system, the low coverage of the Metropolitan in zones with high percentages of poor and extreme poor population restricts most of its connectivity benefits to middle and higher-SES residents closer to the BRT infrastructure. Nevertheless, Lima's BRT line has one of the longest feeder networks in the region, increasing considerably the coverage of the system in areas otherwise served only by paratransit modes, with variable fares and no physical or fare integration. The comparison between potential accessibility analysis for both the total demand of work trips by public transit and the Metropolitan only shows the contribution the system makes to improving travel conditions throughout its area of influence. Lower SES users, who tend to make a high share of long trips benefit from mean reductions in travel times of over 23% for trips where using the Metropolitan makes sense. Unfortunately, the number of low-SES users that can benefit from making those trips seems to represent only a limited share of the demand.

From an inclusion perspective, the limited coverage of the system in the lowest socio-economic areas is a significant constraint for achieving wider social inclusion. In addition, the marked

division between the degree of accessibility provided by the BRT and traditional public transport in the city suggests a disadvantage in travel conditions for users of traditional transit. Such disadvantage is reflected by the aggregated accessibility analysis within constraints of limited ridership at the time of collection of the data.

Given low-ridership, such as those reflected by the JICA 2012 database, the Metropolitano seems to play the role of stemming the tide of an otherwise generalized increase in travel costs for work trips by public transport. This calls for considerations of integration between mass transit other forms of public transport to extend benefits in travel time reductions to other destinations in the city. Examples of integrated fare collection and complementary operational designs incorporating mass and collective transport systems in the region such as Bogotá, Santiago, and Cali have shown that increasing coverage can be compatible with a reduction in transfer costs and commuting fares. In the case of Lima, consideration should also be given to differentiated fares for those of lower income in peripheral areas of the city that enable better access at more affordable prices. Recent examples in the literature suggest that alleviating travel costs for longer trips for the poor can enable better physical access a higher disposable income for low-SES users.

Our accessibility analysis only reflects the potential access to formal job opportunities without considering skills matching. This is an important limitation of the study that although restrict scaling up and cross-sectorial policies for improving access to employment, reflect a spatial and social segregation that produces economic exclusion for those worse-off. Considering the land-use patterns and concentration of formal employment around the Metropolitano, as well as the high number of productive housing, actual job accessibility benefits may be limited to those in higher SES brackets. However, due to limited data on jobs, the effect of the BRT on firm creation and location of employment centers could not be analyzed within the scope of this paper. Future research should consider how the BRT systems may affect firms, and thus job locations and the potential role for complementary land-use strategies that support accessibility of opportunities with various skills requirements in lower-SES areas, particularly those not yet covered by the mass transit system. In particular, the integration of transit infrastructure with the formal-informal continuum observable in housing, transport supply and employment in Lima needs to become a policy priority in relation to enabling asset accumulation and access to income-generating opportunities. Creation of dedicated and quality spaces around the stations for informal commerce, relocation of informal activities and incentives for small firm's development in proximity to the BRT in line with the concept of TOD are relatively low-cost actions that can increase the social and economic benefits of the infrastructure investments already in place.

In this line, the scaling up of the potential benefits of the Metropolitano for accessibility requires not only transport-related interventions, but also integrated policies in the land-use and employment sectors that support access by low-SES populations to the opportunities in the areas that have become more accessible after the implementation of the system. From a policy perspective, it is necessary to acknowledge the social value of investments such as BRT and their integration with the structure of the city and socially differentiated needs. If access to efficient transit is approached as a social policy, it may be possible to devise new forms for improving access to the system supported by results such as the ones in the Metropolitano-only scenario.

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