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Mexico City's suburban land use and transit connection: The effects of the Line B Metro expansion

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ABSTRACT

Over the past half century, government agencies in Mexico City have invested heavily in high-capacity public transit, particularly the 225-km Metro system. Nearly all of this investment has been in central locations of the metropolis. Only recently has service coverage been extended into the periphery, which has accounted for the majority of postwar metropolitan population growth. The Metro's Line B, which opened in phases in 1999 and 2000, significantly expanded Metro coverage into the densely populated and fast-growing suburban municipality of Ecatepec. Comparing travel behavior and land use measures at six geographic scales, including the investment's immediate catchment area, across two time periods—six years before and seven years after the investment opened—this paper investigates the effects of one of the first and only suburban high-capacity transit investments in Mexico City. While the investment sparked a significant increase in local Metro use, most of this increase came from people relying on informal transit, rather than cars. This shift reduced average transit expenditures and travel times for local residents. However, it also increased government subsidies for the Metro and had no apparent effect on road speeds. In terms of land use, the investment increased density around the stations but appears to have had little to no effect on downtown commercial development, where it might have been expected to have a significant influence. In short, the effects of Line B demonstrate much of the promise and problem with expanding high capacity transit service into the suburbs. Ridership is likely to be high, but so too will be the costs and subsidies, while the effects on car ownership and urban form are likely to be modest.

1. Introduction

Over the past two decades, governments and development agencies have invested significantly in high-capacity transit like subways and bus rapid transit (BRT) in Asian, Latin American, and African cities. Beijing went from having just two subway lines in 2000 to having one of the world's largest metro systems and, every year, dozens of new BRT lines open in cities around the world. Concerns over economic competitiveness, congestion, sprawling development, pollution, and accessibility for the poor and middle class have driven these investments. Despite the increased deployment of high-capacity transit—also called mass rapid transit—far less research has evaluated its impact in developing-world cities than in American and European ones. Most of the existing literature, moreover, is either descriptive or recommends a specific technology—generally BRT—based on costs and passenger volumes. There is a small, almost entirely cross-sectional body of empirical work focused on determinants of mode choice on existing systems or the relationship between proximity to rail or BRT and land values. Even less work investigates the land use and travel impacts of transit investments in the suburbs, where developing-world cities are growing most rapidly and which tend to be poorer and more densely populated than in Europe or the US. Yet impacts of transit investments almost certainly vary in areas with different spatial patterns, land use regulations, travel habits, and income levels.

To help fill this research gap, this study focuses on the effects of one of the earliest suburban high-capacity transit investments in Mexico City: Line B of the city's 225-km Metro network. Over the past half century, the Mexican government has invested heavily in high-capacity public transit, particularly the Metro, and more recently BRT and commuter rail. Although several recent investments have been in the fast-growing periphery, service outside of central areas of the Federal District remains quite sparse. Line B, which opened in phases in 1999 and 2000, significantly expanded Metro coverage into the densely populated and fast-growing suburban municipality of Ecatepec. Average annual system-wide Metro boardings, however, have remained fairly steady despite high residential densities, low incomes, and low car ownership in the investment's service area. Why has a well-used investment in

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a dense and largely transit-reliant community failed to spark a notable increase in aggregate transit ridership? To what extent has Line B influenced local land use patterns and travel behavior around the investment and in the region's downtown? What do these findings imply for current Metro, commuter rail, and BRT investment plans in Mexico City and other parts of the world?

2. The influence of high-capacity transit on travel behavior and land use

The effects of high-capacity transit investments are strongly related to the city and neighborhood where they are built. While precise causal relationships are complex and intertwined (Cervero and Kockelman, 1997; Holtzclaw et al., 2002), dense, diverse land uses with pedestrian friendly design tend to increase transit ridership by increasing the speed, convenience, and reliability of transit while reducing the attractiveness of driving, due to congestion and higher parking and other costs. People who prefer transit, due to income constraints or personal preference, may also tend to live in dense, diverse, transit-friendly areas (Cervero, 2007; Chatman, 2009; Mokhtarian and Cao, 2008).

Perhaps the most common expression of the land use and transit connection is that of the critical relationship between dense settlement patterns, high transit use, and economically successful transit systems (Guerra and Cervero, 2011; Meyer et al., 1965; Newman and Kenworthy, 2006; Pushkarev and Zupan, 1977; Seskin et al., 1996). More than any other measures, dense concentrations of people and jobs strongly promote high transit use—a finding that holds across transit systems and cities (Gomez-Ibanez, 1996; Guerra and Cervero, 2011; Liu, 1993; Taylor et al., 2009), neighborhoods (Baum-Snow and Kahn, 2005, 2000; Holtzclaw et al., 2002), transit stations (Cervero, 2006; Guerra et al., 2012; Kuby et al., 2004) and individuals and households (Ewing and Cervero, 2010; Frank et al., 2008; Zhang, 2004). Density not only increases the probability that people choose transit over other modes; it increases the total number of origins and destinations in a transit system's catchment area. Below a certain density threshold, neither changes in density nor transit investments are likely to have much influence on transit use (Newman and Kenworthy, 2006; Pickrell, 1999). High-capacity transit needs even denser concentrations of people and jobs.

In developing-world cities, however, even the most remote neighborhoods often surpass these minimum density thresholds. In Mexico City, for example, the average population density in the surrounding State of Mexico is 126 people per hectare, well above threshold densities established in the US for even the highest-capacity heavy rail systems (Guerra and Cervero, 2011; Pushkarev and Zupan, 1977). Despite transit-friendly built environments, most developing-world cities and their residents have difficulty financing subways and metro systems. Perhaps as a result, a significant portion of the literature on developing-world cities focuses on what type of high-capacity transit is most cost-effective, given limited resources (Fouracre et al., 2003; Gwilliam, 2002; Hidalgo, 2005).

In terms of influencing development and settlement patterns, high-capacity transit tends to have the largest impact in places where real estate markets are strong, government regulations and financing are supportive, and the accessibility benefits of new service are high. In US cities, these conditions have been most prevalent in downtown locations, where indeed transit has tended to have the largest development impacts (Boarnet and Crane, 1997; Cervero and Landis, 1997, 1995; Giuliano, 2004; Huang, 1996; Porter, 1998). Similarly, London's Underground and commuter railways increased commercial development in central London, but also contributed to central depopulation (Levinson, 2008). In addition to a tendency to have a stronger influence on downtown development, new rail transit has primarily influenced land use and transit use in cities that are already dense. Investigating the influence of new transit stations in sixteen cities from 1970 to 2000, Baum-Snow and Kahn (2005) found the effects of new rail on transit use, population density, and home values were much larger in denser, more centralized cities like Boston and Washington, D.C. than in cities like San Jose and Buffalo. Even in dense, centralized regions with rail systems and strong real estate markets, however, job and population growth have been faster away from transit stations than around them (Cervero and Landis, 1997; Lang, 2000). Thus while transit has increased centralized development, it has not necessarily prevented decentralized development.

In places like Mexico City, real estate markets, land use, and regulations are different from in US cities. Although Fouracre et al. (2003) and Gwilliam (2002) identify increased development and economic activity downtown as important impacts of high-capacity transit in developing-world cities, suburban impacts may be as important or even more so. For one, the white-collar workers associated with downtown commercial developments rarely use transit in Mexico City. One of the largest concentrations of office towers is in the notoriously transit-inaccessible Santa Fe. For another, suburban neighborhoods tend to have strong, though-often-informal real estate markets particularly for housing, light and weakly enforced regulations, and high transit mode share. This suggests that investments may bring large accessibility benefits and produce significant land use impacts in suburban neighborhoods. On the other hand, these impacts may be diffuse and insufficient to spark new housing or commercial development, since many rail and BRT riders access stations by local bus or informal transit.

3. Informal transit, the Metro, and the Line B expansion

The Mexico City Metropolitan Area is dense and has high transit ridership. The average neighborhood population density is 145 residents per hectare, while people live in neighborhoods with an average of 165 residents people per hectare (59 and 67 residents per acre respectively). Approximately two thirds of all trips rely on public transportation. In this sense, Mexico City conforms to the most commonly referenced and strongest aspect of the transit and land use connection. The majority of residents and households, however, rely on *colectivos*, privately owned and operated minibuses and minivans that provide public transportation services. Privately provided medium-capacity transit has been a prominent feature of the urban landscape since a series of trolley strikes beginning in 1914 prompted entrepreneurs to convert Ford model T's for passenger transit (Davis, 1994, Chapter. 2; Islas Rivera, 2000, Chapter. 6). Over time, the scope and scale of privately-provided informal transit has expanded. On an average day in 2007, 11.3 million trips, 52% of all vehicular trips[1], relied on *colectivos* for at least part of the journey. Thirty two percent relied exclusively on this mode (INEGI, 2007).

Despite being one of the world's largest and heavily most used metro systems, Mexico City's publicly owned and operated Metro is a newcomer and light-weight, compared with privately provided transit. The first 13 km of the now 225-km network opened in 1969 (Sistema de Transporte Colectivo, 2012). Over the past three decades, it has carried about four million trips per weekday. Although most Metro trips are multimodal, Islas Rivera et al. (2011) estimate that the Metro was the primary mode for fourteen

[1] The metropolitan household travel survey does not include pedestrian trips.

Fig. 1. *Colectivo* transfer station next to suburban Metro station, Ecatepec (2012).

percent of trips in both 1994 and 2007. The Metro, busy day and night, particularly during the long morning and evening peaks, provides high-capacity trunk-line service in the center of the metropolis while *colectivos* provide feeder and local service throughout the metropolis, including densely populated suburban areas with networks of narrow and congested roads. This combined service has made Mexico City a case study for well-integrated transit and land use (Cervero, 1998). Of the 19% of vehicular trips that involved the Metro in 2007, 70% also involved a *colectivo*. Large *colectivo* transfer hubs are common around subway stations, particularly terminals (Fig. 1). Another 14% of Metro trips involved public buses, light rail, and other vehicular modes.

Since the Metro opened, most population growth has been in areas without Metro service outside of the Federal District. From 1970 to 2010, the Federal District has accounted for just 17.5% of the increase in total metropolitan residents. At the time of the 2010 Census, 56% of metropolitan residents lived in the surrounding states of Mexico and Hidalgo. These residents are particularly reliant on informal transit. Nevertheless, 18% of their trips—just a little below the metropolitan average—also involve the Metro. As a result, average daily boardings are particularly high at terminal stations (Fig. 2).

Despite rapid peripheral development, the government has only recently begun to invest in suburban high-capacity transit. Of the only eleven Metro stations in the State of Mexico, eight are on Line B, which provides Metro service into the northeast. The 24-km Line B opened in two phases in 1999 and 2000 at a total investment cost of $1.3 billion in 2013 US dollars (Gwilliam, 2002, p. 113). It runs underground from east to west along the northern half of the center of the Federal District before emerging and expanding northeast into Ecatepec along the *Avenida Central*. As in many peripheral municipalities, residents of Ecatepec are poorer, have lower car ownership rates, and live in more densely populated neighborhoods than the metropolitan average (INEGI, 2007). The municipality has also grown rapidly over the past four decades. As one of the earliest of the very few suburban high-capacity transit investments in Mexico City, Line B can shed light on the likely effects of future suburban Metro, BRT, and commuter rail expansions.

4. Measuring the impacts of the Line B Metro expansion

For the past three decades, average annual Metro boardings have fluctuated around 1.4 billion (Fig. 3). After a period of modest decline from 1994 to 1999, aggregate annual boardings appear to increase as a result of the opening of Line B. At the end of 1994, however, the devaluation of the Mexican peso triggered an economic crisis. Furthermore, the Metro more than doubled its fares from 40 centavos to 1 peso in December, 1995 (Wirth, 1997). It is extremely difficult, if not impossible, to disentangle the effects of Line B on aggregate annual Metro boardings from these simultaneous shocks. Perhaps more importantly, many of the riders who boarded on Line B stations would still be riding the Metro in the absence of Line B, but boarding at different stations. Focusing on changes in travel behavior and land use before and after the investment at different spatial geographies, however, helps separate the likely effects of Line B from larger metropolitan and regional trends.

This study relies on the National Statistics and Geography Agency′s two most recent large-scale household travel surveys in the Mexico City Metropolitan Area (INEGI, 2007, 1994). Conducted in 1994 and 2007, these surveys provide detailed information on household composition, income, and daily travel geocoded by household location, trip origin, and trip destination to the Census Tract. Between the two survey dates, two other high-capacity transit investments opened: Metrobus 1, the city′s first BRT line which runs for 30 km along the central *Avenida de los Insurgentes*, and Line 8, which runs southeast. Neither investment is close enough to Line B to have had much of an influence on local settlement or travel patterns there. Furthermore, no significant policy or infrastructure changes occurred in Line B′s catchment area that would differentiate it from other metropolitan areas.

Therefore, this paper theorizes that relevant changes in households and household travel behavior around Line B that differ systematically from metropolitan, regional, and other geographically relevant trends are directly attributable to the Metro investment. Since a transit investment might be expected to affect travel speeds, costs, mode choices, trip destinations, land uses at origins and destinations, as well as the types of households that locate around it, each is treated a separate dependent variable. Table 1

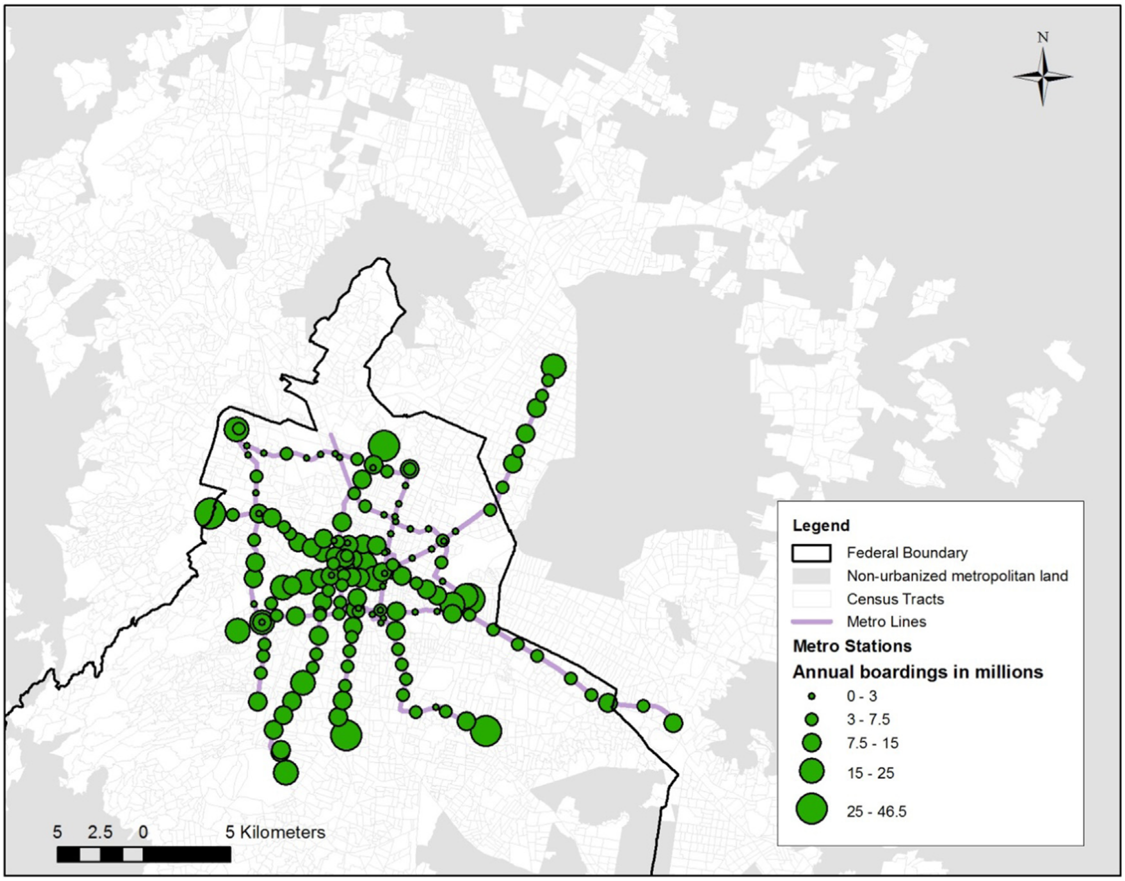

Fig. 2. Annual boardings (millions) by Metro station in 2005 (Sistema de Transporte Colectivo, 2012).

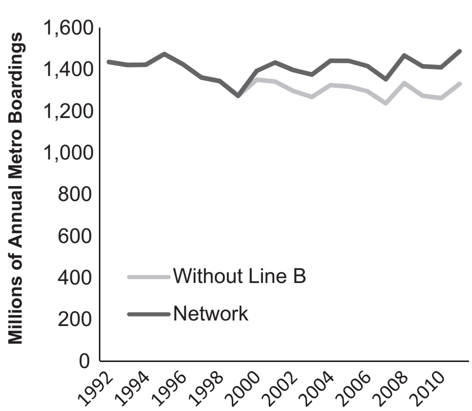

Fig. 3. Metro system annual boardings in millions, 1994–2011 (Sistema de Transporte Colectivo, 2012).

Table 1
Sample of average weekday trips made by households located in each of the six geographic areas of analysis. Data from (INEGI, 2007, 1994).

Geography	1994	2007
1 km from Line B	1157	1518
In Ecatepec	10,278	15,552
1 km from Metro	24,910	40,266
2nd ring	41,336	66,157
In Mexico State	49,792	102,498
In metropolis	125,738	231,514

provides the number of trips recorded by the 1994 and 2007 household travel surveys at each of six geographies analyzed: (1) within a kilometer of a suburban station of Line B, (2) in the surrounding municipality of Ecatepec, (3) in boroughs and municipalities that are a similar distance from the downtown, (4) in the State of Mexico, (5) in the entire metropolitan area, and (6) within a kilometer of any Metro station[2]. Fig. 4 maps these geographies, which are defined by household location, rather than trip origins or destinations.

To test whether the changes in households and household travel behavior are statistically different across geographies, statistical models are fit to pooled data from 1994 to 2007 on households and their average weekday travel choices. Predictor variables include dummy variables for the year, geographic location, and an interaction between the year and geographic location. Due to the nature and distribution of the dependent variables, this study employs four model functions: (1) binomial logit for discrete binary outcomes, such as whether a trip uses the Metro; (2) ordinary least squares for continuous variables, such as the average trip speed; (3) left-censored Tobit for joint discrete and continuous outcomes, such as households' vehicle kilometers traveled by car per day (VKT); and (4) Poisson regression for the one count variable, the number of trip segments on a *colectivo*.

Each model tests a variation on the following null hypothesis:

$$\boldsymbol{E}(\boldsymbol{Y}_i|\boldsymbol{G}_{1i},\ \boldsymbol{G}_{2i},\boldsymbol{D}_i,\ \boldsymbol{G}_{1i}\times\boldsymbol{D}_i)$$
$$\boldsymbol{H}0:\boldsymbol{\mu}=0,\ \boldsymbol{p}>0.05$$

where $\boldsymbol{E}$ is a logit, Tobit, OLS, or Poisson expectation function; $\boldsymbol{Y}$ is one of several dependent variables expected to be influenced by Line B, such as travel speeds and Metro use; $\boldsymbol{G_1}$ is a dummy variable to indicate whether the household resides within a

[2] Residents are considered to be within 1 km of the station if the centroid of their Census Tract is within a kilometer of the geographic center of the station.

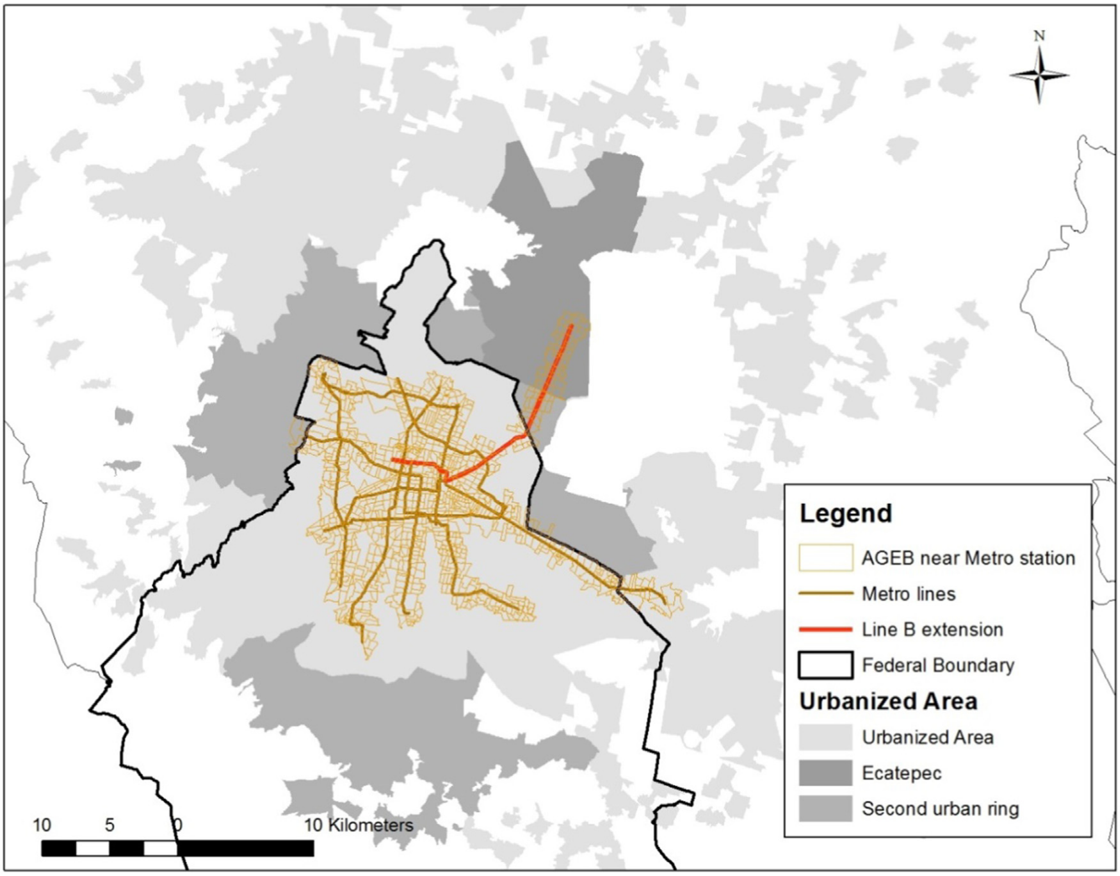

Fig. 4. Geographic areas of analysis for study.

kilometer of where suburban Line B stations will be or are located; $\boldsymbol{G_2}$ is a dummy variable to indicate whether the household resides within one of the five control geographies being tested; $\boldsymbol{D}$ is a dummy variable that indicates the year; and $\boldsymbol{i}$ denotes a household, trip, or household member. $\boldsymbol{\mu}$ is a coefficient estimate for the interaction of $\boldsymbol{G_1} \times \boldsymbol{D}$

To avoid reporting the outputs of several dozen statistical models, an asterisk indicates whether the change in outcomes over time around the newly opened Line B stations are statistically significant with 95% or more confidence for changes in each of the five control geographies[3].

5. Findings: the impacts of the Line B Metro expansion

5.1. Influence on travel

Residents within a kilometer of Line B′s stations were nearly twice as likely to use the Metro on a given trip in 2007 as in 1994 (Table 2). This change was statistically greater than the growth in all other geographies studied. The probability of using just the Metro for a trip increased even more dramatically from 1% in 1994 to 24% in 2007. After Line B opened, residents near Line B were more than twice as likely to use the Metro as an average metropolitan resident and eight times more likely to rely exclusively on the Metro. The proportion of trips by all residents of Ecatepec using the Metro increased a more modest 11% from 0.24 in 1994 to 0.27 in 2007. This increase was statistically different from the changes in Metro use in the second ring, which increased 1%, and the rest of the State of Mexico, which saw a decline in Metro mode share.

Table 2
Proportion of average weekday trips relying partially or exclusively on the Metro in 1994 and 2007 by geography of household location.

Geography	Metro and other mode		Percent change	Metro only		Percent change
	1994	2007		1994	2007	
1 km from Line B	0.24	0.43	82.6%	0.01	0.24	3697.2%
In Ecatepec	0.24	0.27	11.2%[a]	0.01	0.04	392.6%[a]
1 km from Metro	0.24	0.30	26.3%[a]	0.10	0.14	47.5%[a]
2nd ring	0.18	0.19	1.3%[a]	0.00	0.02	373.2%[a]
In Mexico state	0.19	0.18	−3.7%[a]	0.00	0.01	252.1%[a]
In metropolis	0.18	0.19	3.3%[a]	0.02	0.03	25.7%[a]

[a] The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better. See Section 4 for a formal description of the hypothesis tested.

The increase in Metro use has primarily corresponded to a decrease in *colectivo* use, although Line B also may have also had a smaller, localized impact on car use. The total proportion of trips using *colectivos* declined between 1994 and 2007 in all six geographies studied (Table 3). So did the average number of *colectivo* routes used per trip. This change was statistically more pronounced around Line B stations than in other geographies. Ecatepec also had a statistically significant reduction in *colectivo* use. By contrast, private car use increased in all geographies (Table 4). This growth was particularly pronounced in Ecatepec and throughout the rest of the State of Mexico. Relative to the rest

[3] Full model outputs are available upon request.

Table 3
Proportion of average weekday trips relying on *colectivos* and average number of *colectivo* routes used per trip in 1994 and 2007.

Geography	Used *Colectivo* 1994	Used *Colectivo* 2007	Percent change	*Colectivo* segments 1994	*Colectivo* segments 2007	Percent change
1 km from Line B	0.74	0.29	−61.3%	0.95	0.32	−66.4%
In Ecatepec	0.76	0.52	−31.7%[a]	0.98	0.60	−38.6%[a]
1 km from Metro	0.46	0.37	−19.9%[a]	0.55	0.43	−22.6%[a]
2nd ring	0.69	0.55	−20.9%[a]	0.89	0.69	−22.2%[a]
In Mexico state	0.69	0.54	−21.6%[a]	0.87	0.65	−25.0%[a]
In metropolis	0.61	0.52	−16.1%[a]	0.78	0.64	−17.7%[a]

[a] The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better. See Section 4 for a formal description of the hypothesis tested.

Table 4
Proportion of average weekday trips relying on cars and average per capita vehicle kilometers traveled (VKT) per trip in 1994 and 2007.

Geography	Car trips 1994	Car trips 2007	Percent change	VKT per trip 1994	VKT per trip 2007	Percent change
1 km from Line B	0.21	0.29	37.6%	1.42	1.77	24.3%
In Ecatepec	0.14	0.21	50.7%	1.04	1.53	46.7%
1 km from Metro	0.29	0.31	7.5%[a]	1.04	1.27	21.9%
2nd ring	0.22	0.29	32.9%	1.13	1.53	35.6%
In Mexico State	0.19	0.26	36.1%	1.14	1.59	39.2%
In metropolis	0.24	0.29	21.3%[b]	1.10	1.47	33.2%

[a] The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better.

[b] Significant at the 90% confidence level. See Section 4 for a formal description of the hypothesis tested.

Table 5
Average trip speeds in kilometers per hour (KPH) for all trips and by public transportation in 1994 and 2007.

Geography	Avg. speed (KPH) 1994	Avg. speed (KPH) 2007	Percent change	Avg. transit speed (KPH) 1994	Avg. transit speed (KPH) 2007	Percent change
1 km from Line B	14.02	13.17	−6.1%	12.97	13.33	2.7%
In Ecatepec	12.87	12.59	−2.1%	12.40	12.43	0.3%[a]
1 km from Metro	10.79	10.36	−4.0%	9.72	9.77	0.6%[a]
2nd ring	11.85	11.28	−4.8%	11.05	10.59	−4.1%[a]
In Mexico State	13.00	12.38	−4.8%	12.49	11.93	−4.5%[a]
In metropolis	11.91	11.36	−4.6%	11.16	10.75	−3.7%[a]

[a] The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better. See Section 4 for a formal description of the hypothesis tested.

of Ecatepec, the area near Line B saw a smaller percent increase in car use, but the difference was not statistically significant. If Line B has had any effect on car use, it has marginally constrained its growth in a localized area of a municipality where car use has been rising rapidly. The growth rate in car use around Line B was statistically higher than around other Metro stations and higher than the metropolis on average.

The Line B investment appears to have influenced average travel speeds, but only for trips by public transportation, more of which use the Metro (Table 5). Although the difference was not statistically different from any other geography, average travel speeds by all modes declined more quickly around Line B than away from it. By contrast, the speed of trips by public transit (including bus, Metro, and *colectivo*) increased at a statistically significant rate around Line B, as well as around all other Metro stations and in Ecatepec. The rest of the metropolis saw a 4.6% decrease in average speeds by all modes, including public transportation. In addition to increasing transit travel speeds, Line B has had a direct impact on passengers' finances since the Metro is less expensive than *colectivos*. The inflation-adjusted average cost of transit per trip and per kilometer decreased by close to one-third around Line B (Table 6). This change was significantly greater than changes over time at all other geographies, where cost per trip increased. The cost per kilometer increased in the metropolis as a whole, but decreased by 14% around Metro stations. This decrease around Metro stations was significantly smaller than the decrease around Line B.

Table 6
Average total expenditure in inflation-adjusted 2007 pesos on public transportation per trip and by kilometer in 1994 and 2007.

Geography	Total cost 1994	Total cost 2007	Percent change	Cost per km 1994	Cost per km 2007	Percent change
1 km from Line B	6.62	4.65	−29.8%	0.85	0.56	−34.3%
In Ecatepec	7.25	7.48	3.2%[a]	0.90	0.95	5.7%[a]
1 km from Metro	3.85	3.92	1.9%[a]	0.97	0.84	−14.0%[a]
2nd ring	6.03	6.59	9.2%[a]	1.01	1.03	1.6%[a]
In Mexico State	7.04	8.00	13.7%[a]	0.98	1.04	5.3%[a]
In metropolis	5.59	6.34	13.3%[a]	0.97	0.95	−2.5%[a]

[a] The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better. See Section 4 for a formal description of the hypothesis tested.

Table 7
Residents per hectare and the percent of residents within one kilometer of the Metro in 1990 and 2005 (National Census 1990, 2005).

Geography	Residents per Hectare 1990	Residents per Hectare 2005	Percent of residents within 1 km of transit 1990	Percent of residents within 1 km of transit 2005
1 km from Line B	162	189	0%	100%
In Ecatepec	141	154	0%	8.1%
1 km from Metro	190	168	100%	100%
2nd ring	151	150	1.8%	5.4%
In Mexico State	109	126	0.4%	2.5%
In metropolis	143	145	16.5%	13.9%

5.2. Influence on urban form

Perhaps the most notable influence of Line B on metropolitan form is that it increased the proportion of residents of the State of Mexico living near the Metro by about five times (Table 7). Despite this large suburban increase, a smaller proportion of all metropolitan residents lived close to Metro stations in 2005 than in 1990. Most recent population growth has occurred in large, commercially constructed housing developments on the periphery (Guerra, 2013, Chapter 4; Monkkonen, 2011). Furthermore, population density has decreased around most other Metro stations, as indeed it has in most of the Federal District. In sum, the metropolis has grown much more rapidly away from the Metro than around it. While Line B appears to have had significant local effects, these are modest in relation to overall trends in settlement patterns.

To visualize where localized effects are likely to have occurred, Figs. 5 and 6 map the density of trips using Line B by household location and by destination location for non-home trips. Most Line

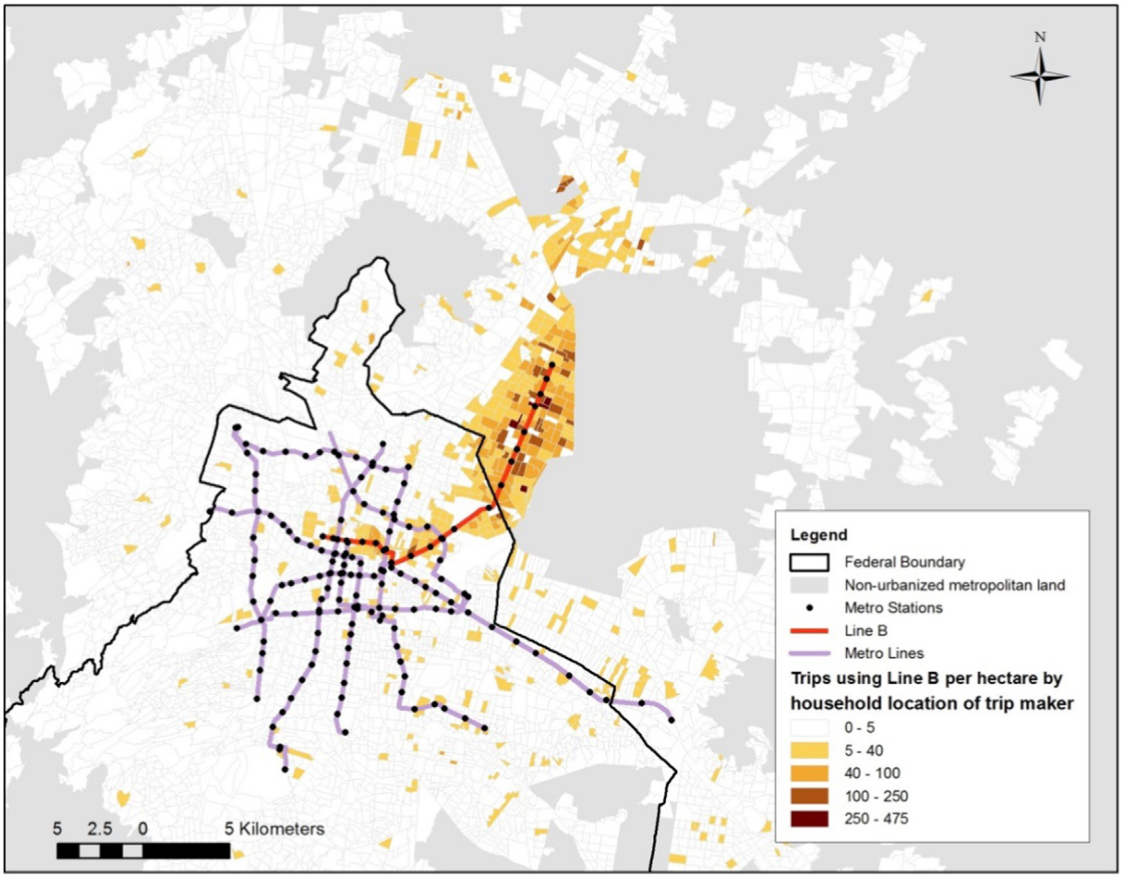

Fig. 5. Trips using Line B per hectare by household location of trip maker (INEGI, 2007).

B users live within three kilometers of the line and use it to travel to central locations in the Federal District. That said, there are some concentrations of homes that rely on Line B in the Federal District as well as some destination hubs near stations in Ecatepec. Nevertheless, the primary land use effects of Line B most likely relate to housing in the northeast and commercial uses in the central area.

Indeed, residential densities increased significantly more for households living around Line B than for households in other geographies (Table 8). Fig. 7, taken from an overpass above Ecatepec station, shows the typically dense two- and three-story residential and commercial developments that are common around Line B and throughout much of Ecatepec. Average household incomes decreased more near Line B than in the rest of Ecatepec but less than around other Metro stations. In addition to losing residents, neighborhoods around Metro stations have likely lost some wealthier households and attracted poorer ones who put a greater value on good transit access. Nevertheless, households around Metro stations in 2007 remained wealthier than the metropolitan average. Unfortunately, data limitations in 1994 prevented an analysis of changes in rent and home values over time.

Line B′s influence on trip destinations, and thus its likely impact on central urban form, is less pronounced. In general, the proportion of all trips, including work trips, to the urban center—measured here as the four most central boroughs of the Federal District—decreased from 1994 to 2007 (Table 9). This decline has been less pronounced around Line B, where the proportion of work trips to the center actually increased. If Line B has had much impact on central commercial space, it has likely been small and difficult to quantify. In short, the investment appears to have spurred significant residential growth around stations but probably had limited impact on central development. That said, the increased number of residents, coupled with increased central work trips, led to an even larger overall uptick in the total number of central trips. Despite this increase, the land use effects are questionable. Metro users do not tend to work in the large commercial developments that are often associated with downtown growth around transit and are therefore unlikely to influence this type of construction. Insufficient commercial land use data precluded a more direct approach to addressing this question.

6. Conclusion

The primary influence of Line B has been to reduce travel times and average expenditures on public transportation for households around the investment and throughout Ecatepec. Residents in neighborhoods within a kilometer of stations saved 1.5 min and 2 pesos per trip on average public transit trips (including those that did not use the Metro) relative to 1994 and even more relative to changes in other geographies. These savings come primarily from households making trips to central locations in the metropolis. Lower costs and faster speeds have encouraged a significant increase in Metro use and population density around the investment. On an average weekday in 2007, residents of Ecatepec generated 65,000 more Metro trips than in 1994. In terms of mode, Line B has primarily drawn ridership from *colectivos* with little observable influence on rapidly growing car use. This conforms to existing findings and expectations (Baum-Snow and Kahn, 2005; Crôtte et al., 2011, 2009; Duranton and Turner, 2009; Fouracre et al., 2003). Since high-capacity transit creates less congestion, less pollution, and fewer collisions per trip than informal public transportation, this shift has public benefits.

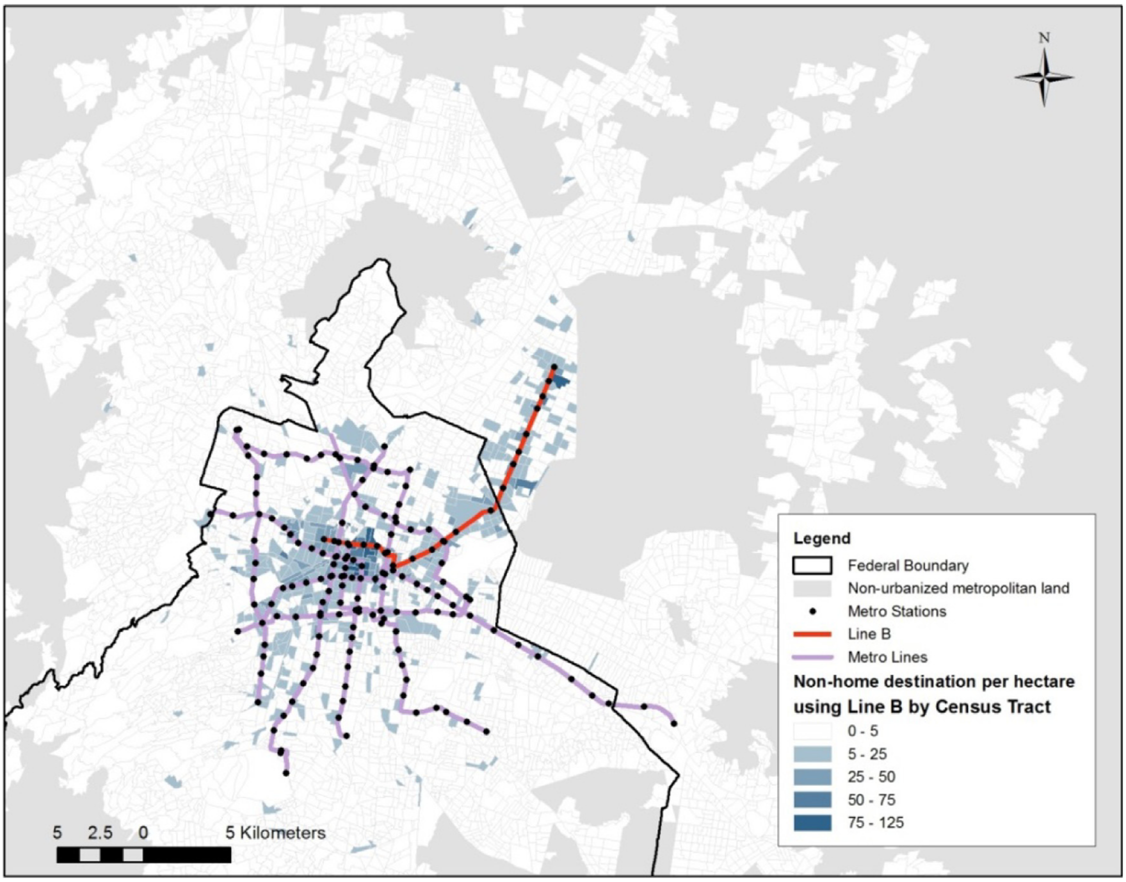

Fig. 6. Non-home trip destinations using Line B per acre (INEGI, 2007).

Table 8
People per hectare in average household's neighborhood and average household income in 1994 and 2007.

Geography	People per hectare		Percent change	Monthly income**		Percent change
	1994	2007		1994	2007	
1 km from Line B	165	211	27.8%	10,309	10,175	−1.3%
In Ecatepec	158	172	8.8%[a]	7,825	8,453	8.0%[b]
1 km from Metro	210	188	−10.3%[a]	13,569	12,210	−10.0%
2nd ring	176	171	−2.9%[a]	10,032	10,251	2.2%
In Mexico state	148	149	0.4%[a]	9,209	9,176	−0.4%
In metropolis	173	165	−4.5%[a]	10,954	10,534	−3.8%

** In 2007 inflation-adjusted Mexican pesos.

[a] The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better.

[b] Significant at the 90% confidence level.

Perhaps most importantly, the Metro provides high-quality service during peak hours, when congestion significantly reduces travel speeds for other modes.

Despite providing improved service to downtown, Line B has likely had only a limited centralizing effect. In this respect, the land use impacts of Line B have differed from those frequently observed in US cities, where new investments have encouraged downtown commercial development. Although Line B has encouraged more centralized trips, particularly work trips, this effect is not always statistically significant. Even if the effect on travel were significant, a strong impact on urban form would be unlikely. The wealthy white-collar workers associated with high-rise commercial developments rarely use transit and the investment appears only to have influenced transit speeds. This supports Navarro and González's (1990) observation that the Metro likely increased land values in poor neighborhoods but decreased them or had no effect in wealthy areas. As a public policy, suburban Metro expansions appear an ineffective tool for reducing congestion or promoting downtown development, but an effective one for improving travel for low and moderate income households.

It also appears to be an effective way to maintain and increase Metro mode share. Like Ecatepec, many suburban municipalities have lower household incomes and car ownership rates than the metropolitan average. These municipalities are becoming more densely populated over time and continue to absorb most metropolitan growth. Despite the promise of higher ridership, expanding high-capacity transit into the suburbs faces significant challenges. First, providing similar Metro coverage per capita in the State of Mexico as in the Federal District would require at least new 230 km of Metro. At the same cost per kilometer as Line B, that would require $12.4 billion in 2013 US dollars. Given lower population densities in the most peripheral neighborhoods, the actual amount of track and stations needed for equivalent service would be even higher.

Second, without radical and unpopular changes in fare policy, Metro expansions will increase the already burdensome operating subsidy that goes to the Metro. Fare revenues cover around half of operating expenses (Gwilliam, 2002) and a standard fare covers less than a third of the total cost of providing the service (Sistema de Transporte Colectivo, 2012). Expanding high-capacity transit service has had a relatively smaller effect on ridership and fare revenues than on costs. In Ecatepec, 24% percent of trips already used the Metro in 1994. In 2007, this figure increased to 27%. Given the flat fare system, however, only new trips generate new

Fig. 7. View of commercial and housing development from Ecatepec Station on Line B (2012).

Table 9
Proportion of trips and work trips with destinations in the four most central boroughs of the Federal District in 1994 and 2007.

Geography	All trips		Percent change	Work trips		Percent change
	1994	2007		1994	2007	
1 km from Line B	0.17	0.17	−0.6%	0.43	0.45	4.4%
In Ecatepec	0.14	0.12	−12.7%	0.34	0.29	−12.5%
1 km from Metro	0.59	0.51	−12.9%	0.58	0.54	−6.5%
2nd ring	0.13	0.12	−7.7%	0.34	0.29	−15.7%[b]
In Mexico State	0.12	0.10	−15.6%[b]	0.30	0.25	−18.0%[a]
In metropolis	0.26	0.20	−23.7%	0.40	0.33	−18.3%[a]

[a] The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better.
[b] Significant at the 90% confidence level.

revenue. Even residents of the most remote municipalities, well outside of the Metro service coverage, used the Metro during 14% percent of weekday trips in 2007. Each new suburban investment reduces the overall ratio of fare revenue to capital and operating costs, as well as raising the total costs. As a result, systematic attempts to increase Metro coverage will require changes to fare policy or greater subsidies. Since Line B reduced costs for transit users and increased travel speeds, there may be an opportunity to increase fares in conjunction with new investments.

In addition to Mexico City, the effects of Line B offer lessons for other medium and large Latin American, Asian, and African cities with similarly dense suburban environments. Even massive investments in high-capacity public transportation are unlikely to offset the need for informal transportation, particularly for low and moderate income residents, who live in fast-growing neighborhoods outside of the service area. While Line B reduced residents' use of *colectivos* in the direct catchment area, more than half of trips in Ecatepec in 2007 continued to use them. New high-capacity transit both complements and competes with informal transit. High-capacity transit investments may replace informal transit on trunk lines, but feeding these lines will remain a critical function for low- and medium-capacity transit.

Improving informal transit has a significant and somewhat neglected role to play in improving public transportation and reducing car use in Mexico City. Despite the significant loss in the overall informal transit mode share—62% of all metropolitan trips used at least one *colectivo* in 1994, compared to 52% in 2007—more than half of all trips continue to rely on *colectivos*. As a result, even minor improvements, such as safer, more comfortable vehicles or lane or signal priority, will tend to have fairly large and widespread economic benefits. Most of the growth in the share of trips using personal cars, furthermore, appears to have come from *colectivos*. Flexible informal transit does a much better job of connecting a wide array of origins and destinations than centrally focused high-capacity transit. It therefore has a better chance of competing with the private car than the Metro or BRT on the growing number of suburb-to-suburb trips. Line B and similar investments primarily serve trips to downtown locations. In the absence of an extensive reorientation of new commercial and housing development away from the periphery and toward transit or massive expansion of the network, the Metro is unlikely to be able to compete for most trips in the fastest growing areas of Mexico City. Like Line B, individual suburban expansions will likely concentrate housing development and encourage a shift from informal to formal transit in the immediate vicinity, but do little to change overall development patterns or stem the increase in private car use. They will, however, tend to reduce travel times and costs on downtown trips—including a significant portion of work commutes—for the ever-increasing number of low-to-moderate-income suburban households.

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