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Sub-way or the Highway: The effects of transport infrastructure on the density of a city

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Abstract

This thesis studies the impacts of investments on urban highways and subway stations on a city's structural density. I use data from Santiago, Chile, to analyze the effects of the inaugurations of six urban highways and several subway stations between 2001 and 2010 on built-up land. As treatment variables, I use the variation in a network-based accessibility index, which controls for the non-random location of transport infrastructure. Results show that inaugurations of subway stations decrease overall construction density in the neighboring areas by -0,75 percent. In contrast, the opening of urban highways increases square meters built by 1,72 percent. The effects of urban highways on residential and industrial land use are also positive and statistically significant, with coefficients of 1,64 and 1,55 percent. The interacted effect of both infrastructures on the overall construction, services, and commercial purposes suggests a crowding-out type of dynamic. At the same time, for residential and industrial land use purposes, this relation is positive, which indicates complementary dynamics of improvement in infrastructures.

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Contents

List of Tables

List of Figures

1 Introduction

Transport infrastructure has a long-standing relation with density patterns in cities, where reductions in transportation costs lead to a rise in property consumption and prices due to an increase in demand, that ultimately translate into the expansion of the city (Duranton and Puga, 2015). In today's context of climate crisis, understanding the effects of transport infrastructure in the shape of cities is crucial in promoting their sustainable development.

For urban planners, it is a puzzling query what type of transport infrastructure to invest. Theoretically, all of them provide better accessibility to people and firms, but they vary in their effects on city growth. For example, urban highways are often correlated with the sprawl of the city, while subways are commonly associated with fostering urban density (Redding and Turner, 2015; Duranton and Puga, 2014, 2015).

This thesis aims to shed light on the effects of transport infrastructure on density patterns and spatial allocation of economic activity. In particular, it contrasts the impact of two transport infrastructure, subway expansions, and urban highway inaugurations, allowing to study the interacted effect of both. The setting of this study is in Chile's capital, Santiago, were between 2001 and 2010 the government inaugurated over 53 km of subway lines, an increase of 36 percent in the network, and over 200 km of urban highways in different parts of the city (see Figure (2)).

To study the effects of increased accessibility due to the inaugurations of transport infrastructure on built-up land, I use the accessibility variation between blocks within a targeted treated area. These variations distribute continuously over space and are a by-product of the location of the infrastructure. As the treatment has a continuous form, there are no discrete treatment and control groups (Gibbons et al., 2019). Using this network-based accessibility index, while controlling for location and infrastructure fixed effects, helps to control for non-random location of transport infrastructure (Gibbons et al., 2019).

Results show that subway expansions decrease overall built-up land, as well as for residential purposes, by -0,66 and 0,75 percent. In contrast, the effect of subways on service, commercial, and industrial purposes is positive but not statistically significant. On the other hand, inaugurations of urban highways increase surfaces built by 1,72 percent. This type of infrastructure also has a positive and statistically significant impact on residential and industrial land use purposes, with coefficients of 1,64 and 1,55 percent.

To assess the combined impact of subway and urban highway inaugurations, I study the interacted effect of both infrastructures to determine complementary or substituting effects. Results show that the impact of one infrastructure on square meters built depends on the level of change induced by the other transport infrastructure. For the overall construction, services, and commercial purposes, the relation between the two accessibility variables is negative, which suggests a crowding-out type of dynamic. On the other hand, residential and industrial built-up land has a positive and statistically significant relation, where the effect of one transport infrastructure increases with the growth of the second accessibility index. This positive relation indicates complementary dynamics of improvement in infrastructures on square meters built.

The data set used in this thesis includes block-level property information from Chile's Internal Revenue Service (Servicio de Impuestos Internos) for 2001 and 2010. This data set consists of 34.235 blocks within the urban limit and has information on built-up land, surface area, year of construction, and quality indicators. Built-up land changed from 121 km^2 in 2001 to 148 km^2 in 2010, an increase of 22 percent. I also use the Census of 2002 to elaborate baseline covariates.

There is vast evidence regarding the effects of transport infrastructure on intracity outcomes. Investment in highways decentralizes population (Redding and Turner, 2015; Baum-Snow, 2007; Baum-Snow et al., 2017; Garcia-López et al., 2015), decentralizes manufacturing activity (Baum-Snow et al., 2017), also has an effect on population growth in the vicinity of the infrastructure (Baum-Snow, 2007), on employment growth (Duranton and Turner, 2012), and on driving in the city (Duranton and Turner, 2011). On the other hand, investment in subways generates an increase in property prices in the vicinity of the stations (Gibbons and Machin, 2005; Ahlfeldt, 2013; Billings et al., 2011; Bowes and Ihlanfeldt, 2001), as well as decentralization of population (Gonzalez-Navarro and Turner, 2018) and an increase in employment (Mayer and Trevien, 2017).

The first contribution of this thesis is considering the construction of two simultaneous infrastructure, urban highways and subways. This feature allows for analyzing complementary or substituting effects of these infrastructures on different land use. The setting of this thesis allows for an adequate comparison of the impact of both infrastructures, given that they share time and space fixed effects (see Table (A1) and Figure (2)). This research resembles Baum-Snow et al. (2017), which studies the impact of railroad and highway investment in Chinese cities during 1990. They focus on the decentralization of population and industrial production from central cities to suburban and ex-urban areas. They find that radial highways and suburban ring roads reduce the population density in central cities and decentralize the manufacturing activity to peripheral areas of the cities. Also, results show that railroads cause an increase in population as well as growth in the manufacturing industries.

An essential distinction between Baum-Snow et al. (2017) and this thesis is the nature of the transport infrastructure studied. In the Chinese setting, railroads and highways have an intercity focus, while both of Santiago's infrastructure have an intracity purpose. For instance, in Chinese cities, the railroad system is mainly used for freight and long-distance passenger trips.[1] Subways, unlike intercity railways, promote short-distance trips, and are commonly used for commuting purposes.[2] Although both studies focus on the internal composition of the city, these differences in infrastructure may produce different results. For instance, the spatial organization of the population is usually more sensible

[1] Chinas Rail system does not have characteristics of a traditional commuter rail system like the subway (frequent stops, low cost, etc.). The Beijing Suburban Railway is the first system that resembles a subway. It inaugurated in 2008 through 2017.

[2] In Santiago, 2012, almost 40 percent of Subway trips were commuting (SECTRA, 2012).

to subways and roads, while production is more sensible to railroads (Redding and Turner, 2015).

The second contribution of this thesis is the use of micro-data to study the internal composition of the city. Most papers focus on larger geographical areas to assess sub-urbanization, comparing the city center to the outer regions of the city (Baum-Snow, 2007; Baum-Snow et al., 2017). By using the data at a granular scale, it allows assessing the effect in the city and around each type of infrastructure.

The third contribution of this thesis is the density outcome used. To the best of my knowledge, this will be the first study that uses built-up land instead of prices, population, or production to measure density (Redding and Turner, 2015; Duranton and Puga, 2014, 2015). These variables respond differently to shocks, where prices and population react faster to shocks than squared meters built, because of the mobility of these types of capital. Also, an increase in the area built is probably more irreversible than an increase in property prices, and it may have relevant long-term effects because more area built potentially increases the population density of a specific area.

A final contribution of this study is regarding the nature of the highway network. Most of the literature focuses on interstate highways or urban segments of interstate highways. Santiago's urban highway network was planned to provide better connectivity within the city, presenting a new angle to research regarding connectivity within a city and urban transport infrastructure.

The first section of this thesis describes the setting of the city. The next section describes the framework that includes the identification strategy, followed by the dataset description. Last is the result section, followed by the conclusion.

2 Background

This investigation studies the Santiago Metropolitan area (henceforth, Santiago) between the years 2001 and 2010. During this decade, Chile's economy overgrew, increasing from a GDP of 146.574 to 272.874 thousand USD (OECD, 2017), transitioning from an "Upper Middle Income Country" to a "High Income Country" (World Bank, 2019). The Metropolitan region concentrated more than 40 percent of the country's GDP (Banco Central, 2017).

Santiago is located in a valley and has an extension of approximately 837.89 km^2 (INE, 2014), and experienced a population increased from 6.061.185 to 7.112.808 (INE, 2017). Its center has densified and expanded to the East (Bergoeing and Razmilic, 2017; Truffello and Hidalgo, 2015), which vertically densify the North-East fraction of the city (Caballero, 2018), that is also the place where most of the high income and high skill people live. Santiago presents high levels of income inequality (World Bank, 2017; Ministerio de Desarrollo Social, Ministerio de Desarrollo Social), similar to the national level.[3]

Table (1) shows the information of the construction activity in Santiago by purposes. From 2001 to 2010, the total squared km built increased by 23

[3]Chile is in the 20 percent of most unequal countries (World Bank, 2017).

Table 1: Squared meters built by year and purpose

Year	Total	Housing	Commerce	Industry	Services	Education
2001	120.657.711	77.920.964	8.382.147	7.840.796	7.976.153	3.476.116
2010	148.168.826	91.741.385	9.787.649	7.957.255	9.397.934	5.094.262

Notes: Land use aggregated information from the Chilean National Taxing System (Servicio de Impuestos Internos, SII) for the years 2001 and 2010. The total information also considers other land use purposes (others and not considered category).

percent, from 120,7 to 148,2 km^2. Around 70 percent of the built-up land is of housing. Services have the participation of approximately 11 percent; commerce and industries have roughly 7 percent each; while the other purposes present around 3 percent of the total. These shares are relatively constant over time.

Figure (3) presents the distribution of built-up land at an aggregate level. The darker the background color represents a larger variation in squared meters. Red lines indicate urban highways, while black and yellow circles are 2001 and 2010 subway stations, respectively. Panel (a) presents a variation in squared meters built. Darker colors concentrate on the edges of the city, particularly in the north-west. This could be a representation of suburbanization tendencies as found in Baum-Snow (2007) and Baum-Snow et al. (2017).

Panel (b) shows the same variation but controlling for baseline covariates, and it presents slightly different patterns than the previous image. The main difference is in the center of the city, where subway lines and the Costanera Norte intersect. This area is the west fraction of the CBD, which, as mentioned previously, has expanded. The south has a considerable level of growth once controlling for covariates, which could be explained by the subway expansion and the inauguration of the Vespucio Sur highway (further detailed in the next section). Last, this image shows the same development on the west and the north-west as Panel (a). Those areas are the closest points to ports and access to intercity highways, as well as the international airport, located at the intersection of Vespucio Norte and Costanera Norte.

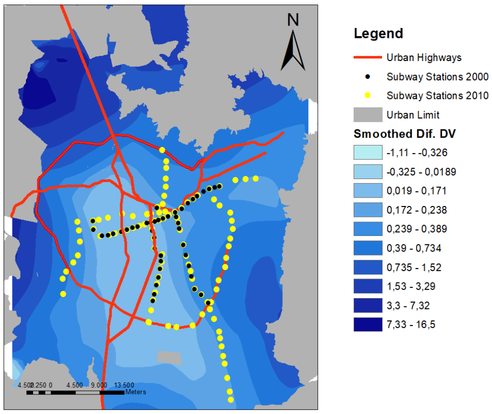
2.1 Transport Infrastructure

Commutes in Santiago transitioned between 2001 and 2010. Table (2) presents information on the mode of transport that people in Santiago used to go to work in 2001 and 2012.

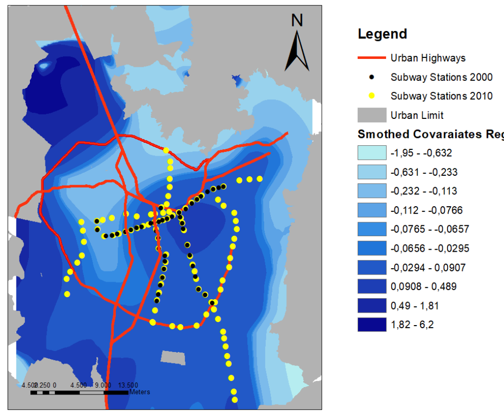
Between 2001 and 2012, private transportation modes increased their share of participation from 30 to 35 percent. Public transportation decreased its participation, changing from 50 to 42 percent of the commutes; however, public transportation remains the most widely used mode of transportation. Bicycles, walking, and other modes, together, increased their participation from 20 to 23 percent.

Figure 1: Smoothed difference in squared meters built (2001 - 2010)

(a) Difference in built-up land (ln)



(b) Difference in built-up land controlling for baseline characteristics



Notes: Own elaboration using Kernel interpolation of built-up land. Information from the SII for 2001 and 2010.

Table 2: Commutes in Santiago 2001 and 2012

Mode	2001 (thousand)	2001 (%)	2012 (thousand)	2012 (%)
Private	1.240	30%	1.991	35%
Public	2.067	50%	2.364	42%
Bicycle	136	3%	287	5%
Walking	543	13%	824	15%
Other	163	4%	187	3%
Total	4.148		5.653	

Notes: Own elaboration. Information from Santiago's Mobility Survey in 2001 and 2012 (Encuesta Origen Destino). Both periods use the same 38 municipalities.

2.1.1 Subway stations

Santiago subways inaugurated in 1975, with 12 stations that connected the political center (La Moneda Palace) to the west. In 2001, the subway network was made of three subway lines, containing 54 stations that made around 40 km. The system encompasses a central line that connects east to west and falls below one of the main avenues in the city, and two lines that ran almost parallel to each other connecting this central artery to the south of the city (see Panel (a) of Figure (2)). At that moment, the subway transported an average of around one million passengers daily (Metro, 2010).

In 2007 the subway system became the central axis of an incorporated public transportation system, Transantiago, that had a unified tariff, with bus-feeder routes that connect with the subway (Gómez-Lobo Echeñique, 2007). This

Table 3: Distance to Transport Infrastructure (km)

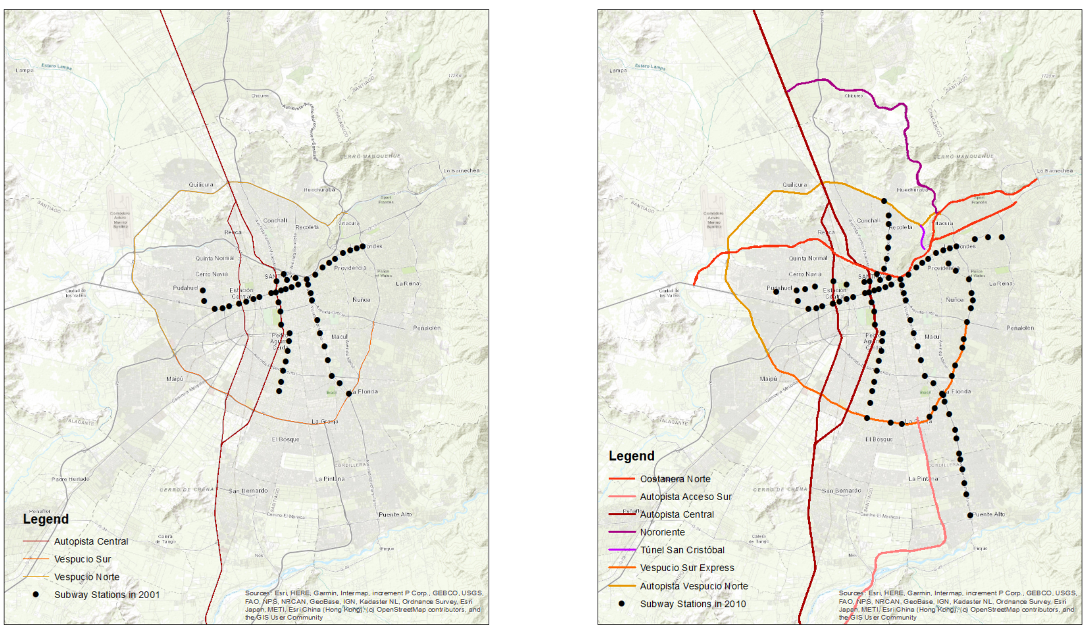
	mean	sd	min	max
Distance to Subway Station in 2010	3,0	3,1	0,0	22,5
Distance to Subway Station in 2001	4,9	3,7	0,0	27,2
Distance to Costanera Norte	8,6	6,0	0,0	24,3
Distance to Autopista Central	5,4	3,7	0,0	19,6
Distance to Vespucio Sur	5,7	4,5	0,0	33,1
Distance to Vespucio Norte	8,3	5,9	0,0	25,3
Distance to Acceso Sur	10,2	6,6	0,0	40,1
Distance to Nororiente	14,4	6,5	0,5	30,2
Distance to Túnel San Cristóbal	12,5	5,7	0,1	27,1
Observations	33751			

Notes: Geo-referenced data from SII.

Figure 2: Santiago's Transport Infrastructure Evolution (2001 - 2010)

(a) Transport Infrastructure 2001

(b) Transport Infrastructure 2010



Notes: Own elaboration. Maps use geo-referenced information on subways and urban highway from the Observatory of cities of the Pontificia Universidad Católica de Chile (Observatorio de Ciudades UC), and the pre-census street shapefile.

alteration made public transport users more reliant on the subway, doubling its demand (Metro, 2010).

By 2010 the government inaugurated over 53 km of subway lines, an increase of 36 percent in the network, now a total of 94 km. The system had 101 stations, 49 of them new; where 29 belonged to 2 new lines, line 4 and 4A (Table (A1)), that passed over Vespucio Sur and connected the south-east fraction of the city (see Panel (b) of Figure (2)). Of the other 20 stations, most of them expanded the network to the north. At this point, the system had over two million trips a day (Metro de Santiago, 2010).

All parts of the city experienced increased proximity to the subway network, where the average distance to a station reduced from 4,9 to 3 km (see Table (3)). In the baseline scenario, the subway network passed through 15 municipalities, while at the endline, it passed through 31 of the total of 40 municipalities that currently make up the Great Santiago area.

2.1.2 Urban highways

Santiago experienced an important investment on urban highways during the 2000s. Between 2000 and 2006, the Chilean government coordinated the construction of 207 km of urban highways in six different projects, valued at 1.582 million USD. One of the objectives of this massive intervention was reducing the infrastructure deficit in the city (Gutiérrez and Fuentes, 2014). This network uses a free-flow toll system (Gobierno de Chile, Gobierno de Chile).[4]

There are two types of urban highways, those built in areas where before there was no transport infrastructure,[5] and those that where low-speed avenues that experienced upgrades in their infrastructure (Congreso Nacional de Chile, 1999), turning them into high-speed urban highways. In the first group of highways are Autopista Costanera Norte, Túnel San Cristóbal, and Acceso Sur. In the second group of highways are Vespucio Sur, Vespucio Norte, and the Autopista Central.

Figure (2) shows a map of Santiago's urban highways. Connecting north to south is the Autopista Central (Autopista Central and General Velasquez), the longest of the urban highways, with an extension of 61,2 km, that passes through 14 municipalities. This urban highway is an extension of the Ruta 5, an intercity highway. Connecting east to west is the Costanera Norte, located in the Northern side of the city, with an extension of 42 km (Costanera Norte and the Kennedy axis). It passes through 10 municipalities, and through this route, you can access the Airport. There is also the Americo Vespucio circle, formed by Vespucio Sur and Vespucio Norte. Together they add up to 53 km of highway, 24 of Vespucio Sur, and 29 of Vespucio Norte.[6] In the south of Santiago is Acceso

[4]A external validity concern is in regards of the cost that car-owners face in Santiago, particularly in the toll of urban highways.

[5]For example, parts of the Costanera Norte go under the Mapocho River, while also, the San Cristóbal Tunnel crosses a hill.

[6]The missing part of the ring road is the Vespucio Oriente project that is still in the bidding stage.

Sur that connects Vespucio Sur with the Ruta 5, an interstate highway. Last is Túnel San Cristóbal, which connects Vespucio Norte with Costanera Norte at the west part of the CBD.

Table (3) summarizes the information of the distances to the nearest point on the highway. Autopista Central and Vespucio Sur present the smallest average distances, with 5,4 and 5,7 km, respectively. It follows Vespucio Norte and Costanera Nortes with 8,3 and 8,6 km, respectively. These four highways present the smallest distances because they cover more significant portions of the city. The northern part of the town, beyond the ring road, has fewer areas within the urban limit compared to the south, explaining the difference in means of highways located in the north. Last, Acceso Sur and Túnel San Cristóbal have more considerable distances on average than the others, with 10,2 and 12,5 km, respectively.

3 Framework

This section begins with a review of the urban land use theory to provide intuitions of the equations used and the results. The classic monocentric city model developed by Alonso et al. (1964), Mills (1967) and Muth (1969), considers a linear monocentric city, where housing and land are allocated endogenously through competitive bidding. This model considers commuting costs that increase linearly with distance to the CBD and where the remainder of the residents' income is consumed in housing. In the residential equilibrium, if a resident moves marginally away from the CBD, then she will experience an increase in commuting costs, as well as a decrease in the cost of housing consumption (marginal cost of commuting equals the marginal cost of consumption of housing) (Duranton and Puga, 2015). The tension between proximity to the CBD and prices, known as the Alonso-Muth condition, translates into a negative price gradient from the CBD. This condition applies directly to house consumption, and inversely to capital intensity in housing (Duranton and Puga, 2015).

When considering accessibility measures instead of distance, the density gradient, which stands for the built-up land gradient, could present a non-monotonical form, because of heterogeneous proximity to transport infrastructure (Baum-Snow, 2007). However, the predictions of the model still apply for density patterns in the city, where better accessibility in an area shortens traveling times to the CBD (Ahlfeldt et al., 2015; Duranton and Puga, 2015; Tsivanidis, 2017). The predictions of the model for firm locations are less direct than for housing (Baum-Snow et al., 2017), where the firms' trade-off is between agglomeration benefits and higher costs due to land prices and wages, which directly depend on commuting costs.

Equation (1) describes the cross-section intracity model that assesses the relation between accessibility, Θ_{it}, and a density outcome, in this study, the sum of squared meters built of block i, in year t (SMB_{it}).

$$\text{SMB}_{it} = \alpha_{it} + \beta * \Theta_{it} + \gamma_i + \delta_t + \epsilon_{it} \tag{1}$$

The allocation of activities depends on the dominance of each gradient, as well as land requirements. Duranton and Puga (2015) provides an extensive analysis of the conditions that allow different distribution of activities in the city. They find three possible equilibriums that depend on commuting costs, land requirements of firms, and the productivity spillover decay. First, when spillovers dominate commuting costs, the city center has only firms while residents are in the suburban areas of the city. On the other hand, when commuting cost dominates spillover effects, all the city is mixed-use, and every worker lives where they work. The third equilibrium includes a mixed-use city center where local workers live, followed by an only commercial area, and last, a single residential area. To empirically assess economic allocation, the same model used to study the overall construction density should apply for all purposes, as developed in Baum-Snow et al. (2017).

An underlying mechanism involves the types of transport infrastructure. When the infrastructure reduces the commuting costs for car users, the development of the city presents a leapfrog pattern (Duranton and Puga, 2015). While, on the other hand, a reduction in commuting costs due to improvements in public transportation would generate centralized growth. Because subway networks, and even bus stops, are usually compacted around the central city, the development would be bounded to that area as well. This mechanism could differ depending on the land use purpose, where the industrial activity will probably be more responsive to urban highways than to subways. While on the other hand, housing and offices will likely respond to both (Redding and Turner, 2015; Tsivanidis, 2017).

In Redding and Turner (2015) is a summary of the standard inference problems in cross-section specification as the one in equation (1). First, the content of the residual vector ϵ_{it} could contain information specific to local characteristics, correlating the treatment variable to the error term. Second, proximity to infrastructure is, for the most part, not assigned randomly to units. Finally, in the presence of general equilibrium effects of transport infrastructure, separating such spillovers from other location time-varying factors requires additional assumptions.

The first problem was corrected by studying the first difference version of equation (1); by doing so, all time-invariant unobserved characteristics will cancel by this variation.

$$\Delta \ln(SMB)_i = \beta_1 * \Delta \ln \Theta_i + \theta X_{i0} + \delta^* + \Delta\epsilon_i \tag{2}$$

For the second identification problem, in the presence of non-random treatment assignment, the literature has mostly used instrumental variables to estimate causal effects, considering three main groups of instruments that satisfy the exclusion and relevance assumptions (Redding and Turner, 2015). First, is the inconsequential units approach were the treatment of specific units is accidental, which means that the treatment assignment does not correlate with unobservable attributes of the area. Second is the planned route instruments that use past network plans as a source of quasi-random variation from the current transport infrastructure. Third, is the historical route IV use old transport routes as a source of variation.

An alternative approach that deals with the non-random scheme location are the network-based accessibility index developed by Gibbons et al. (2019). This index uses the exposure of areas located in a perimeter of the infrastructure as a continuous treatment effect, instead of using a discrete treatment and control group. It consists of the variation in the accessibility measure between blocks within a targeted area. Changes in accessibility between units close to the subways or urban highways are an incidental by-product of the changes in the network (Gibbons et al., 2019). The location of the infrastructure is still potentially endogenous, but the changes in accessibility are not. In this sense, it is similar to the inconsequential units approach.

Their identification assumption states that changes in accessibility are exogenous when controlling for geographical fixed and time-varying infrastructure location effects. They restrict the sample to those areas located within the 20 km radius of the scheme to compare those units near the infrastructure, and, therefore, only blocks that experience increased accessibility (Gibbons et al., 2019).

The identification strategy developed in Gibbons et al. (2019) is well suited for this study because it also considered improvements to an existing network, which, in their case, was the construction of new road schemes in Great Britain (GB) between 1998 and 2007. They, just as in this study, consider discrete transport interventions, small geographical areas and take into account different types of road infrastructure.[7]

Aside from these similarities, there are differences to consider. First, the road network in the base scenario in GB was already developed and dense, and it only expanded by 0.87 percent in the period studied (Gibbons et al., 2019). In Santiago, on the other hand, the highway network is new, and the subway network increased by 36 percent. There is also a difference in regards to the distribution of the expansions of the networks. For GB, inaugurations characterize by being scattered, while for Santiago, the subway expansion, is a radial continuation of the system, and the urban highways network covers the entire city.

These differences in network expansion require adaptation in the treatment assignment criteria. To delimit the treated areas, I restrict the sample to blocks that are between 0 and 1,25, and between 0 and 2 km of the infrastructure, instead of 1 to 20 km as in Gibbons et al. (2019), while also limiting travel times to 75 minutes for any O-D pair (Gibbons et al., 2019). As subways and

[7]They consider new road links, upgraded roads, and roads for which there was an alternative route before, similar to the nature of the urban highways in this study.

urban highways have as objective to improve connectivity in the city, using a smaller impact zone is adequate for determining those treated blocks. I focus on subways stations inaugurated after 2001 and before 2010, while for urban highways, I consider all of them as they were all opened between 2001 and 2010.[8]

Second, there are two simultaneous network improvements in this study versus one in Gibbons et al. (2019). Most areas in the city received improved accessibility from one of the two sources. To study this heterogeneity, I built two accessibility index, one for changes induced by the extension in the subway network, and the second for variations due to inaugurations of urban highways. I will refer to these variables as public and private accessibility, as these infrastructures directly affect traveling for users of public and private transportation. The accessibility index in equation (2) will consider improvement by different infrastructure separately, together with their interaction, as described in the equation (3).

$$\Delta \ln(SMB)_i = \beta_1 \Delta \ln \Theta_i^{Pub} + \beta_2 \Delta \ln \Theta_i^{Pri} + \beta_3 \Delta \ln \Theta_i^{Pub} \Delta \ln \Theta_i^{Pri} + \theta X_{i0} + \delta^* + \Delta \epsilon_i \tag{3}$$

For equations (2) and (3) the dependent variable, $\Delta \ln(SMB)_i$, is the variation in the log of the squared meters built of block i. The treatment variable, $\Delta \ln \Theta_i$, is the change in log accessibility, where changes in public transportation present the notation of Θ_i^{Pub}, and changes in private transportation have the notation of Θ_i^{Pri}. Beta coefficients will be interpreted as percentages, as the independent and the dependent variables are expressed in logarithms. The covariate vector (X_{i0}) includes the distance to the CBD, the natural logarithm of the area of the block, the initial level of the dependent variable (Duranton and Turner, 2012), the initial level of the accessibility index (Gibbons et al., 2019), distance to infrastructure (Gibbons et al., 2019; Tsivanidis, 2017), the population density of the block in the baseline year, and the block average of the census socioeconomic indicator (Baum-Snow, 2007; Mayer and Trevien, 2017). In all the regressions, we report clustered standard errors at an Estraus zone level.[9]

The sample used to assess equation (3) are those blocks located at a 1,25 km perimeter from either infrastructure. While to evaluate the effects of changes in public and private accessibility separately, I use equation (2) for each, considering those blocks between 0 and 2 km of each infrastructure. These buffers permit the parallel trend assumption to holds while also having a larger impact area that allows for the positive effects of improved accessibility to outweigh the negative effects of proximity to infrastructure (Bowes and Ihlanfeldt, 2001).

[8] Nororiente highway is not included in this study as it is an extension of the interstate highway network that mainly passes through provincial areas outside the urban limit.

[9] SECTRA defines these areas based on a four-step simulation model of the equilibrium of the urban transportation system, that uses this particular zoning system (ESTRAUS). Estraus zones aggregate information of SII blocks.

The main effects in equation (3), β_1 and β_2, represent the effects of changes in accessibility by public and private transportation, respectively when the other accessibility index does not change, being equal to zero. The coefficient accompanying the interacted term, β_3, is the slope of the effect on the outcome of changes in an accessibility index for different values in the changes of the other accessibility index. To put it differently, the effect of one variable depends on the value of the other variable, where the impact of improvement in private transportation is $\beta_2 + \beta_3 * \Delta \ln \Theta_i^{Pub}$, which varies with accessibility changes by public infrastructure, $\Delta \ln \Theta_i^{Pub}$. The same happens to the effect of improvement in public infrastructure. For each accessibility index, I estimate the marginal effects evaluated at the 1st, 25th, 50th, 75th, and 99th percentile values of the other accessibility measure (see Table (5) for the percentile values).

Last, concerning the third problem mentioned in Redding and Turner (2015), regarding possible spillover effects between the treated and control group, an additional advantage of using a continuous treatment variable is that it resolves this problem, as there is no longer a control group to contaminate.

The results found in this study are analogous to an intent to treat, given blocks exposure to the infrastructure. By limiting the sample to those areas in the urban limit, this study finds the effects on the intensive margin of the cities expansion.

4 Data

The information for the dependent variable, changes in squared meters built, is provided by the Chilean National Taxing System (Servicio de Impuestos Internos, SII), for different land use purposes. These include commerce, education, housing, industries, and services.[10] For this thesis, I will focus on the total built-up land, which considers all purposes, and also on housing, services and commerce, and industrial purposes. Block-level information, defined by SII, is available for the years 2001 and 2010. For the baseline covariates, I use data from the 2002 Census by the National Institute of Statistics (Instituto Nacional de Estadísticas, INE) that has block-level data. For proximity covariates such as distance to subways, urban highways, and the CBD, I calculate the distance from the infrastructure to the centroid of the block.

The original sample has a total of 48.170 blocks, from which I consider 34.234 blocks within Santiago's urban limit (INE, 2014). This sample remains constant in the time studied, consisting of 42 municipalities that, on average, include 892 blocks. Table (4) summarizes descriptive statistics of blocks and baseline covariates of the sample in the urban limit (first column). The second column has information for those blocks treated by the new subway station, the

[10] The land use purposes are commerce, education, housing, industries (that consists of industrial and mining activity), services (including public administration, offices, and health), a not considered (that includes thing such as eriazo site, agricultural land, forests, not defined and without information), and others (including hotel, motel, sports and recreation, cult and others) (Suazo, 2017).

Table 4: Descriptive Statistics of Baseline Covariates (2002)

	Urban limit	Treated(SW)	Treated(UHW)	Treated(Both)
Area of Block (m^2)	10.970,0	9.552,7	9.544,2	9.563,2
	(80.521)	(23.637)	(55.150)	(50.953)
Radius of Block (m)	44,1	47,2	43,3	44,0
	(39)	(28)	(34)	(33)
Population in Block	140,1	155,1	141,6	143,8
	(194)	(210)	(192)	(199)
Density of Block (population/km^2)	42.012,7	42.754,1	47.548,0	45.737,9
	(353.399)	(416.306)	(415.402)	(419.075)
Households in Block	38,6	45,2	39,4	40,4
	(55)	(64)	(54)	(57)
SES	7,1	7,1	6,8	7,0
	(2)	(2)	(1)	(2)
CBD	11.586,3	9.414,2	10.074,5	10.234,8
	(5.902)	(4.574)	(4.724)	(4.845)
# municipalities	42,0	21,0	35,0	37,0
# Estraus zones	594,0	158,0	294,0	362,0
Observations	34237	6951	14798	18114

Mean coefficients; SD in parentheses

Notes: The table shows descriptive statistics of covariates using information from the 2002 population Census and blocks characteristics. The first column has information of blocks in the urban limit. The second and third column has information for those blocks in the 2 km buffer from a new subway station (SW) or an urban highway (UHW), respectively. The fourth column has information for those blocks in the 1,25 km buffer from a new subway station or an urban highway.

third column has information for blocks treated by highways, and the fourth column has statistics of those blocks treated by either infrastructure. Because of the extension of the urban highway network, it's treated sample includes more blocks than the subway's treated sample, with 14.794 compared to 6.947 blocks, respectively. The sample used to study equation (3) is in the fourth column, which considers 18.112 blocks.

Blocks treated by new subway stations are different from those treated by urban highways. The sample in the 2 km buffer from subway stations is larger in surface and population, with a surface area of 9.552,7 square meters and 155,1 inhabitants on average, compared to the sample treated by urban highways that have a surface area of 9.544,2 and 141,6 inhabitants on average. Those blocks located near subway extensions also have more households on average than the treated sample by urban highways, with 45,2 versus 39,4. However, population density in the subways treated area is of 42.754,1, which is smaller than the population density of blocks in the treated area of urban highways of 47.548,0. The socioeconomic status of blocks is similar between the subway and urban highway treated groups, with blocks being on average in the 7th decile. Units that received a subway are closer to the CBD than those treated by urban highways, with 9,4 km and 10,1 km on average.

The sample of blocks treated by both infrastructure, with summary information in the fourth column, resembles those statistics in column three, of blocks treated by urban highways. These similarities makes sense as the blocks treated by urban highways represent 82 percent of blocks treated by either transport infrastructure.

4.1 Accessibility index

The accessibility index used in this study is known as potential accessibility, and it measures the exposure to improvements in the infrastructure of block i, as described in the equation (4). It is a weighted sum of the proximity of all destinations j, from origin i, where proximity is a decreasing function of minimum journey times, T_{ij}, through the transport network (Gibbons et al., 2019).[11] Information on accessibility is at the Estraus zone level that is an aggregation of SII blocks.

$$\Theta_i = \sum_{i \neq j} T_{ij}^{-1} * w_{j0} \tag{4}$$

The weight factor w_{k0} is a measure of employment intensity in destination j (Niehaus et al., 2016). In this study, I use the information on land use from the Chilean National Taxing System (Servicio de Impuestos Internos) at the Estraus zone level for the year 2000. The weight factor w_{k0} considers all constructed surfaces destined to services and commercial purposes, divided by the block's area (Niehaus et al., 2016).

I use three versions of the accessibility index. The first is the public transport accessibility index, which considers variation in traveled times in public transportation, because of subway inaugurations. The second is the private accessibility index that only studies the effect of changes in traveled times induced by the opening of urban highways. The third index is the generalized accessibility measure, which considers changes in traveled times by the openings in both infrastructures simultaneously.

The information on travel times comes from the origin-destination matrix constructed from the 2017 pre-census street network and a subway network built from the georeferenced subway lines and stations from the Observatory of cities of the Pontificia Universidad Católica de Chile (Observatorio de Ciudades UC). Then with GIS Network Analysis Tools, I combined the street network with the subway network, adapting them to the city's layout in 2010 and 2001.[12] Based on Ahlfeldt (2013), the decision rule for the calculation of travel times in both periods is as follows:

$$T_{ij}^{z} = \begin{cases} \text{if } z = 2001, & min(\frac{D_{ij}}{V^{Car}}; min(Public\ Transportation(PT))) \\ \text{if } z = 2012, & min(\frac{D_{ij}}{V^{Car}}; min(Public\ Transportation(PT))) \end{cases} \tag{5}$$

[11] Travel times are a proxy for travel costs (Gibbons et al., 2019).

[12] Considering alterations to the urban highway network, subway network, and peripheral roads.

$$PT_{ij}^{z} = \begin{cases} \text{if } z = 2001, & min(\frac{D_{is}}{V^{Bus}}; min(\frac{D_{is}}{V^{Walk}}) + min(\frac{N_{se}}{V^{Subway}}) + min(\frac{D_{ej}}{V^{Walk}})) \\ \text{if } z = 2012, & min(\frac{D_{is}}{V^{Bus}}; min(\frac{D_{is}}{V^{Bus}}) + min(\frac{N_{se}}{V^{Subway}}) + min(\frac{D_{ej}}{V^{Bus}})) \end{cases} \quad (6)$$

The variable D in equations (5) and (6) stands for the distance traveled on the street network, while N is the distance traveled in the subway network, and last, V stands for the traveling speed of the different travel modes. Speed parameters are those documented in official reports of average travel speed of all transportation modes (SECTRA, a,b). Table (A3) in the Appendix has a summary of the speed parameters used, all from the pre-treatment scenario except for the urban highways. This information comes from Santiago's 2001 Mobility Survey (in Spanish, "Encuesta de Movilidad") for the morning peak period.

Passengers decide their travel mode based on travel time minimization. In 2001, if a commuter chooses to travel by car, she does so from origin i to destination j. On the other hand, if the passenger decides to use public transportation, she may either use the bus or the subway. This last decision consists of a trip to the nearest station of origin s, followed by shortest-path travel through the subway network to station e, and a final trip from the end station to the destination j. The decision-making process is the same in 2010, except that the subway decision includes traveling by bus instead of walking.[13]

The accessibility index described in equation (4) increases when travel times decrease, and when the baseline value of employment intensity is larger. Table (5) summarizes the changes in the log accessibility index, where the most substantial difference on average was by the public transportation system of 0,168. Changes in private accessibility in the period studied are of 0,028, while the changes in the combined accessibility measure changed on average by 0,062. As mentioned in the Framework, the percentile values are latter used to evaluate the marginal effects of the interacted term of equation (3).

Figure (3) shows the accessibility index and their respective treated areas for public and private transportation improvements. Both panels use the same 2-kilometer buffer (Gibbons and Machin, 2005). Darker colors stand for greater accessibility, which varies within the treated area. There is an inconsistent pattern of the accessibility index in the neighboring areas of the infrastructure. This scattering is expected for these types of index (Gibbons and Machin, 2005), providing a visual representation that there are differences in accessibility for those units treated.

[13]This alteration takes into account that in 2007 the public transport system changed, with combined tariff and feeder buses that connected with the subway network, changing the decision-making process of individuals traveling on public transportation.

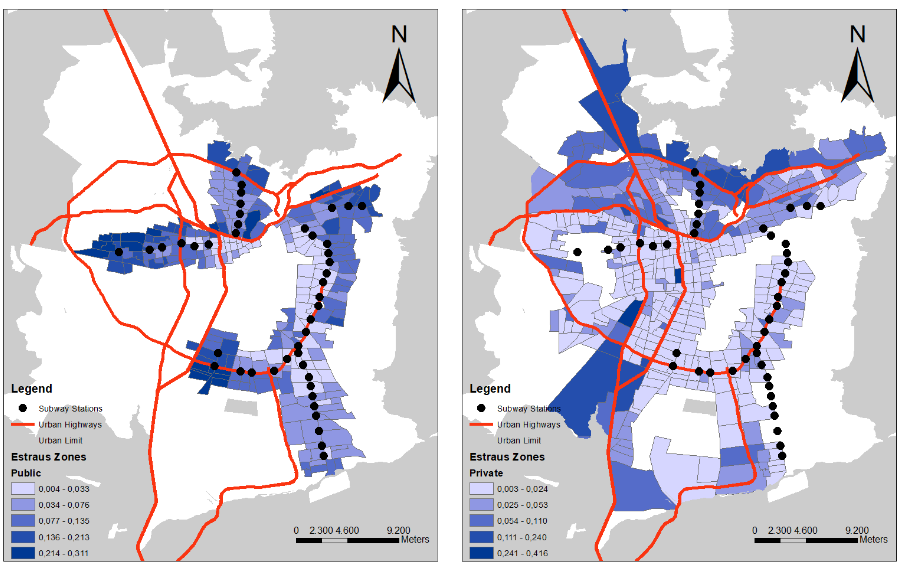
Table 5: Difference in log accesibility (2001 - 2010)

	$\Delta(\ln(Acc_{Pub}))$	$\Delta(\ln(Acc_{Pri}))$	$\Delta(\ln(Acc_{Both}))$
P(1)	0,007	0,005	0,005
P(25)	0,064	0,012	0,014
P(50)	0,128	0,019	0,031
P(75)	0,238	0,036	0,073
P(99)	0,535	0,104	0,385
Mean	0,168	0,028	0,062
SD	0,137	0,025	0,080

Notes: The table shows summary statistics of changes in log accessibility for the sample of blocks in the 1,25 km buffer from a new subway station or an urban highway.

Figure 3: Changes in log accesibility (2001 - 2010)

(a) Public Transportation **(b)** Private Transportation



Notes: Own elaboration. Maps use built-up land from the SII and geo-referenced information on subways and urban highway from the Observatory of cities of the Pontificia Universidad Católica de Chile (Observatorio de Ciudades UC), and the pre-census street shapefile.

5 Results

5.1 Testing for Parallel Trends

To test for preexisting trends, I use aggregated data instead of microdata because 2001 is the earliest version of this dataset on square meters built, while information at the level of Estraus zones (which aggregates block information) begins in 1990. Table (6) shows the results of the regression of squared meters built from 1990 to 1995 on the changes in accessibility between 2001 and 2010, controlling for the accessibility level in 2001 and proximity to the infrastructure (Gibbons et al., 2019). Columns (1) and (2) have the coefficients for subway and highway inaugurations, respectively, which considers a 2 km buffer from each infrastructure. Columns (3) and (4) use the sample of blocks that are treated by both infrastructures, those within a 1,25 km buffer from either infrastructure. Column (3) the combined effect of improved accessibility by transport infrastructure, while column (4) studies accessibility made by each infrastructure separately (as in equation (3)). Tables (A4), (A5) and (A6) have the same specifications as Table (6) applied to residential, service and commerce, and industrial land use purposes.

Table 6: Testing for Parallel Trends (1990-1995)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	-0,18			-0,66
	(0,56)			(0,49)
$\Delta(\ln(Acc_{Pri}))$		-0,33		1,86
		(0,58)		(1,24)
$\Delta(\ln(Acc_{Both}))$			-0,77	
			(0,66)	
$\Delta(\ln(Acc_{Pub})) \times \Delta(\ln(Acc_{Pri}))$				-6,89
				(4,24)
2001 Acc.(Θ_{2001})	Yes	Yes	Yes	Yes
Distance to SW	Yes	No	Yes	Yes
Distance to UHW	No	Yes	Yes	Yes
Observations	261	407	362	362
R^2	0,0547	0,2074	0,3987	0,5128

Standard errors in parentheses

Notes: Table reports coefficients from Estraus-level regression and robust standard errors (clustered at Estaus level), weighted by the zone's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure and accessibility in 2001. The sample studied are those areas located in the urban limit and within the 2 km buffer for Columns (1) and (2), and of 1,25 km buffer for Columns (3) and (4). Columns (1) and (2) study blocks treated by public and private transportation individually, while Columns (3) and (4) study the effects on blocks treated by either infrastructure.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Most coefficients are not statistically different from zero, which means that there is no impact of improvements in the infrastructure on square meters built before their inaugurations. Of the four tables that assess parallel trends, only two coefficients are statistically significant, first in column (3) of Table (A5) with a coefficient of -1,48 for accessibility changes by both infrastructure, and for the main effect of public transportation in column (4) of Table (A6). This last one is the most worrisome of these results, given that it assesses equation (3). The main effect of public transportation for industrial land use has a coefficient of -5,77 percent, which is statistically significant at a 5 percent level. For this reason, results regarding the impact of public transportation on industrial land use, for those areas treated by both infrastructure, should be carefully interpreted.

The final buffers sizes are of 2 km for the separate specification (columns (1) and (2)), and 1,25 km for the joint specification (columns (3) and (4)). These values derived from the pre-trends assessment. When assessing with buffers of 1, 2, 3, and 4 km, the parallel trend assumption did not hold for equation (3) or (2) (results available upon request).

5.2 Main Results

Table (7) reports the results for equation (2) and (3), considering subway inaugurations in column (1), highway inaugurations in column (2), a combined accessibility index in column (3), and in column (4) the separate study of public and private accessibility. The main difference between these specifications, aside from the models and the infrastructure they assess, is in the sample used. Columns (1) and (2) consider blocks near the respective infrastructure, so their results indicate the effect of the improvement of the infrastructure on blocks close to them. For columns (3) and (4), results show the effect of changes in accessibility on those areas close to some of the two improved infrastructure.

The dependent variable in all columns is the change of square meters built expressed in logarithms, from 2001 to 2010. All specifications control for the initial level of accessibility, distance to CBD, distance to subways and highways, and block baseline characteristics, such as population density, household socioeconomic information, population and number of households. This set of controls is the preferred specification chosen from results in Tables (A7), (A8), (A9), and (A10) in the Appendix, which progressively includes covariates.

Increased accessibility due to subway inaugurations has a negative and significant impact on built-up land at the 5 percent level (column (1) of Table (7)). A one percent improvement in accessibility is associated with a reduction in 0,75 percent of built-up land. The size of the coefficient is sensitive to the inclusion of covariates, ranging from 0,06 in the specification with no covariates, to -1,12, results in columns (1) and (3) of Table (A7).

On the other hand, the effect of urban highways on built-up land is positive and statistically significant at a 1 percent level. For an increase in one percent in the accessibility index, construction increases by 1,72 percent. This coefficient is sensitive to the inclusion of covariates, changing from 4,53 in the specification with no covariates, gradually decreasing to 1,72 percent when controlling for the preferred set of covariates, results in columns (1) and (5) of Table (A8).

Columns (3) and (4) of Table (7) allow assessing the effect of both transport infrastructure on the density outcome. The coefficient of the combined accessibility index is in column (3) that considers the impact of a generalized

Table 7: Effects of accessibility on built-up land (2001-2010)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	-0,75**			-0,16
	(0,29)			(0,20)
$\Delta(\ln(Acc_{Pri}))$		1,72***		2,61***
		(0,48)		(0,78)
$\Delta(\ln(Acc_{Both}))$			0,31	
			(0,24)	
$\Delta(\ln(Acc_{Pub})) \times \Delta(\ln(Acc_{Pri}))$				-4,45
				(2,87)
2001 Acc.(Θ_{2001})	Yes	Yes	Yes	Yes
Block Controls	Yes	Yes	Yes	Yes
Distance to CBD	Yes	Yes	Yes	Yes
Distance to SW/UHW	Yes	Yes	Yes	Yes
Observations	13175	21014	18057	18057
R^2	0,0898	0,1943	0,1832	0,2077

Standard errors in parentheses

Notes: Table reports coefficients from block-level regression and robust standard errors (clustered at Estaus level), weighted by the block's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, and block baseline characteristics (population density, household socioeconomic information, population and number of households). The sample studied are those areas located in the urban limit and within the 2 km buffer for Columns (1) and (2), and of 1,25 km buffer for Columns (3) and (4). Columns (1) and (2) study blocks in the treatment area of public and private transportation, respectively, while Columns (3) and (4) study the effects on blocks treated by either infrastructure.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

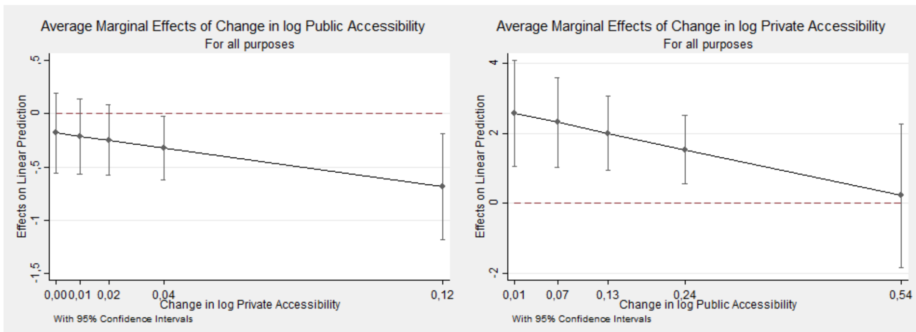
improvement of accessibility on those blocks in the treated area of either transport infrastructure. A one percent increase in accessibility turns into a 0,31 percent increase in built-up land, which is not statistically different from zero. This coefficient and its significance are sensitive to the addition of covariates, ranging from 0,31 to 1,11, in columns (5) and (1) of Table (A9).

Column (4) in Table (7) assess equation (3), which allows studying the interacted effects of each transport infrastructure. The main effects for public transportation accessibility are not statistically significant from zero, with a coefficient of -0,16, meaning that changes in public accessibility, when changes in private accessibility are zero, are not significant. On the contrary, the main effect for private accessibility is 2,61 percent and statistically significant at a 1 percent level, indicating that the impact of changes in accessibility due to urban highways, where public transport accessibility did not change is positive and statistically significant.

The interacted term in columns (4) is the slope of the marginal effects of changes in accessibility by one infrastructure on changes in the accessibility of the other infrastructure. This coefficient is of -4,45, and it is not statistically different from zero. Panel (a) of Figure (4) presents the effects of improved public accessibility for values of private accessibility. All coefficients are negative, with the highest one of -0,18 for blocks that experience small changes in private accessibility, decreasing up to -0,68 for large changes in private accessi-

Figure 4: Average Marginal Effects for all land use purposes

(a) Change in log Public Accessibility **(b)** Change in log Private Accessibility



Notes: Figure presents the average marginal effects of changes in log accessibility on $\Delta(\ln(SMB))$ evaluated in the 1st, 25th, 50th, 75th, and 99th percentile value of the other change in accessibility variable (summarized in Table (5)). This specification comes from column (4) of Table (7), that controls for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, and block baseline characteristics (population density, household socioeconomic information, population and number of households). The sample studied are those areas located in the urban limit and within the 1,25 km buffer of either infrastructure.

bility. The effect is statistically significant for those blocks that experience large improvements in private accessibility, which means that accessibility improvement by subway expansions has a negative impact on square meters built when combined with substantial changes in accessibility because of urban highways.

Results displayed in Panel (b) of Figure (4), which mirrors those of Panel (a), show positive and, for the most part, statistically significant effects on build-up land when in the presence of improvement of public accessibility. The largest coefficient, of 2,57, is in those blocks that experienced small changes in public accessibility, which is statistically different from zero. This effect decreases with the growth of the public accessibility index, reaching the lowest value of 0,23, which is no longer statistically different from zero. The negative slope observed in both panels of Figure (4), suggests that the effect of accessibility improvement by these transport infrastructures have a crowding-out type of dynamic, where considerable improvements in accessibility by one transport infrastructure reduces the impact of the other on squared meters built.

From this set of results, it is possible to establish that accessibility improvements from private transport infrastructure, for the most part, have a positive and significant effect on squared meters built. While, on the other hand, changes in public accessibility have a negative impact on neighboring areas, although, when considering the presence of changes in private accessibility, this negative effect requires substantial changes in accessibility to be statistically significant.

5.3 Results for different land use purposes

In this section, I apply to the different land use purposes the same specification used for the main results in Table (7). In Table (8) are the results for housing, Table (9) has the results for commerce and services, and last, in Table (10) are the results for industrial land uses.

Table 8: Effects of accessibility on built-up land for housing purposes (2001-2010)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	-0,66***			-0,38
	(0,21)			(0,23)
$\Delta(\ln(Acc_{Pri}))$		1,64**		-1,33
		(0,73)		(1,21)
$\Delta(\ln(Acc_{Both}))$			0,11	
			(0,29)	
$\Delta(\ln(Acc_{Pub})) \times \Delta(\ln(Acc_{Pri}))$				12,95***
				(4,19)
2001 Acc.(Θ_{2001})	Yes	Yes	Yes	Yes
Block Controls	Yes	Yes	Yes	Yes
Distance to CBD	Yes	Yes	Yes	Yes
Distance to SW/UHW	Yes	Yes	Yes	Yes
Observations	13041	20759	17839	17839
R^2	0,0493	0,0576	0,0511	0,0916

Standard errors in parentheses

Notes: Table reports coefficients from block-level regression and robust standard errors (clustered at Estaus level), weighted by the block's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, and block baseline characteristics (population density, household socioeconomic information, population and number of households). The sample studied are those areas located in the urban limit and within the 2 km buffer for Columns (1) and (2), and of 1,25 km buffer for Columns (3) and (4). Columns (1) and (2) study blocks treated by public and private transportation individually, while Columns (3) and (4) study the effects on blocks treated by either infrastructure.

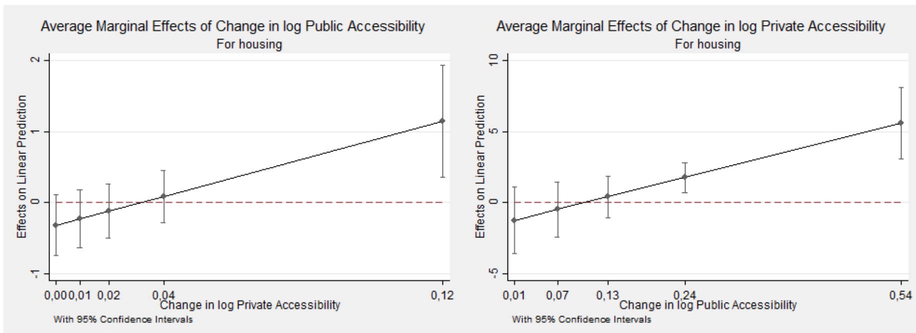
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table (8) displays results for residential land use.[14] The effect of subway inaugurations on built-up residential land is of -0,66 percent, while urban highways have an effect of 1,64 percent; both results are statistically significant (columns (1) and (2)). Column (4) presents the main effects for both accessibility measures that are negative and not statistically significant, which means that the impact of either infrastructure does not affect built-up land when the other accessibility measure does not change over time. From this same specification, the interacted term has a coefficient of 12,95, significant at a 1 percent level, which stands for the relation of the effect of one accessibility variable when the other one increases. Figure (5) visually presents this relation for both variables, where the positive slopes suggest complementary dynamics between both accessibility

[14] These results resemble those found in Table (7), which studies overall construction density, which is an expected outcome given that housing is the primary type of construction purpose in Santiago (Table (1)).

Figure 5: Average Marginal Effects for housing

(a) Change in log Public Accessibility **(b)** Change in log Private Accessibility



Notes: Figure presents the average marginal effects of changes in log accessibility on $\Delta(\ln(SMB))$ evaluated in the 1st, 25th, 50th, 75th, and 99th percentile value of the other change in accessibility variable (summarized in Table (5)). This specification comes from column (4) of Table (8), that controls for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, and block baseline characteristics (population density, household socioeconomic information, population and number of households). The sample studied are those areas located in the urban limit and within the 1,25 km buffer of either infrastructure.

Table 9: Effects of accessibility on built-up land for services and commercial purposes (2001-2010)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	0,30			0,04
	(0,48)			(0,52)
$\Delta(\ln(Acc_{Pri}))$		-0,80		2,30*
		(1,22)		(1,31)
$\Delta(\ln(Acc_{Both}))$			-0,65*	
			(0,36)	
$\Delta(\ln(Acc_{Pub})) \times \Delta(\ln(Acc_{Pri}))$				-13,85*
				(7,48)
2001 Acc.(Θ_{2001})	Yes	Yes	Yes	Yes
Block Controls	Yes	Yes	Yes	Yes
Distance to CBD	Yes	Yes	Yes	Yes
Distance to SW/UHW	Yes	Yes	Yes	Yes
Observations	6049	9483	8171	8171
R^2	0,0630	0,1102	0,1134	0,1239

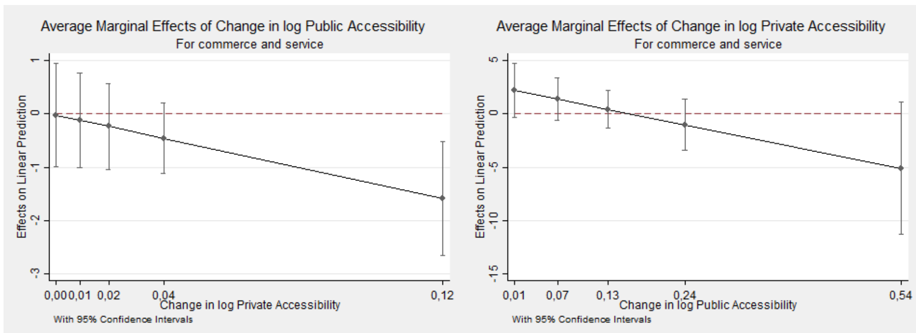
Standard errors in parentheses

Notes: Table reports coefficients from block-level regression and robust standard errors (clustered at Estaus level), weighted by the block's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, and block baseline characteristics (population density, household socioeconomic information, population and number of households). The sample studied are those areas located in the urban limit and within the 2 km buffer for Columns (1) and (2), and of 1,25 km buffer for Columns (3) and (4). Columns (1) and (2) study blocks treated by public and private transportation individually, while Columns (3) and (4) study the effects on blocks treated by either infrastructure.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 6: Average Marginal Effects for services and commercial land use

(a) Change in log Public Accessibility **(b)** Change in log Private Accessibility



Notes: Figure presents the average marginal effects of changes in log accessibility on $\Delta(\ln(SMB))$ evaluated in the 1st, 25th, 50th, 75th, and 99th percentile value of the other change in accessibility variable (summarized in Table (5)). This specification comes from column (4) of Table (9), that controls for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, and block baseline characteristics (population density, household socioeconomic information, population and number of households). The sample studied are those areas located in the urban limit and within the 1,25 km buffer of either infrastructure.

Table 10: Effects of accessibility on built-up land for industrial purposes (2001-2010)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	0,08			-0,36*
	(0,50)			(0,20)
$\Delta(\ln(Acc_{Pri}))$		1,55**		-1,50
		(0,60)		(1,06)
$\Delta(\ln(Acc_{Both}))$			-0,19	
			(0,35)	
$\Delta(\ln(Acc_{Pub})) \times \Delta(\ln(Acc_{Pri}))$				10,34***
				(3,57)
2001 Acc.(Θ_{2001})	Yes	Yes	Yes	Yes
Block Controls	Yes	Yes	Yes	Yes
Distance to CBD	Yes	Yes	Yes	Yes
Distance to SW/UHW	Yes	Yes	Yes	Yes
Observations	1916	3085	2513	2513
R^2	0,0574	0,1000	0,0846	0,1127

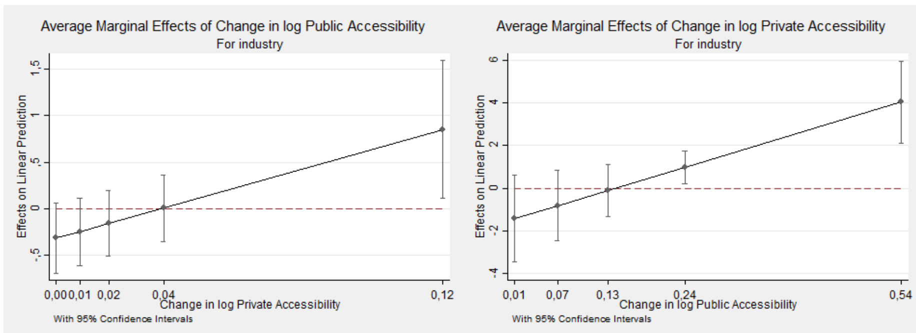
Standard errors in parentheses

Notes: Table reports coefficients from block-level regression and robust standard errors (clustered at Estaus level), weighted by the block's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, and block baseline characteristics (population density, household socioeconomic information, population and number of households). The sample studied are those areas located in the urban limit within the 2 km buffer for Columns (1) and (2), and of 1,25 km buffer for Columns (3) and (4). Columns (1) and (2) study blocks treated by public and private transportation individually, while Columns (3) and (4) study the effects on blocks treated by either infrastructure.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 7: Average Marginal Effects for industrial land use

(a) Change in log Public Accessibility **(b)** Change in log Private Accessibility



Notes: Figure presents the average marginal effects of changes in log accessibility on $\Delta(\ln(SMB))$ evaluated in the 1st, 25th, 50th, 75th, and 99th percentile value of the other change in accessibility variable (summarized in Table (5)). This specification comes from column (4) of Table (10), that controls for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, and block baseline characteristics (population density, household socioeconomic information, population and number of households). The sample studied are those areas located in the urban limit and within the 1,25 km buffer of either infrastructure.

measures. Panel (a) shows the effect of public accessibility on built-up residential land for different values of variation in private accessibility. For low levels of variation in private accessibility, the effect of public accessibility is negative and not statistically significant. This effect gradually increases with changes in private accessibility, reaching a coefficient of 1,12 percent. Panel (b) also presents negative and not significant coefficients of private accessibility when in the presence of small changes in public accessibility. As the relation between both accessibility measure is positive, the effect of private accessibility grows with the size of the change of public accessibility, with a significant effect of 5,60 percent increase on built-up land for large changes in public accessibility.

Table (9) presents results for services and commercial land use, which show that the effect of infrastructure is not statistically different from zero, with coefficients of 0,30 and -0,80 for public and private accessibility respectively, in columns (1) and (2). The signs of these effects are the opposite of the results found in Tables (7) and (8), with private accessibility being negative and public accessibility positive. Column (4) presents an effect of a 2,30 percent increase in squared meter built for a 1 percent change in private accessibility when there are no changes in public accessibility. This result is statistically significant, while, on the other hand, the main effect of public accessibility is 0,04 percent, which is not statistically different from zero. The interacted coefficient in column (4) is of -13,85, statistically significant at a 10 percent level, indicating a negative slope in the figures that display those marginal effects. Figure (6) presents this negative relation on both panels, which suggests a crowding-out type of dynamic, where increases in one accessibility measure reduce the effect of the other accessibility measure on square meters built. Results in both panels show that most marginal effects are not statistically different from zero. Panel (a) shows the marginal effects of public accessibility, where most coefficients are negative and not statistically significant, except for one result displayed; for large increases in private accessibility, the impact of public accessibility is of -1,59 percent, statistically different from zero. Panel (b) presents no statistically significant effects of private accessibility on commercial and services square meters built.

Table (10) displays the results of industrial land use purposes on accessibility measures. The effect of private accessibility is of 1,55 percent, and it is statistically significant. In contrast, the effect of public accessibility is not statistically significant, with a coefficient of 0,08 (results found in columns (2) and (1), respectively). Column (4) presents a negative and significant main effect for public accessibility of 0,36 and a negative but not statistically significant main effect for private accessibility of 1,50. The interacted coefficient is of 10,34, significant at a 1 percent level, indicating a positive relation between accessibility variables.[15] Both panels in Figure (7) present this positive slopes. Panel (a) shows that the effects of public transportation improvements are not statistically significant. At the same time, some results in Panel (b) have positive and statistically significant coefficients of improvement in private transportation. The effect of private accessibility becomes progressively increasing with the change in public accessibility up to a coefficient of 4,04 percent, when in the presence of large changes in public accessibility. Results of the interaction of the accessibility variables on industrial land use also suggest complementary effects between both transport infrastructures.

To summarize the results in this section, the effect of subway inaugurations on residential land use is negative and statistically significant. In contrast, on commerce, service, and industrial purposes, the impact is positive but not statistically significant. On the other hand, the effects of improved accessibility by the inauguration of urban highways are positive and statistically significant on housing and industrial land use. At the same time, this effect is negative and not statistically significant for commerce and services. Also, the results of the interacted effect of both transport infrastructure present complementary dynamics in build-up residential and industrial land. For square meters built of commerce and services, growth in one accessibility measure has a crowding-out effect on the other variable.

These results lead to the conclusion that the inauguration of subway stations reduces built-up residential land. This unexpected result could be an indication of a spatial reallocation of activities in the city. For instance, in a city where agglomeration benefits outweigh commuting costs, the city presents a segregated layout, where the city center has only firms, and the surrounding areas have only residential properties (Duranton and Puga, 2015). In this context, when

[15] It is important to mention the possible confounding effects of the previous trend found in Table (A6), so to study results in column (4), particularly the effects of public accessibility carefully.

commuting costs decrease, the relative importance of productivity spillovers increases, fostering this segregated distribution. Results on the effects of subway suggest this may be the case, considering the negative impact on housing and the positive, but not statistically significant, coefficients on service, commercial, and industrial land use.

The identification strategy used in this thesis provides causal results of the effect of infrastructure for those blocks within a 2 km buffer. In an extended version of the city center, defined by accessibility principles, these blocks are part of the city center. For this reason, this study can identify impacts on locations in the city center. Still, it is not able to empirically assess the effects of transport infrastructure in areas beyond the city center.

6 Conclusion

This thesis studies the effects of the inauguration of subway stations and urban highways on built-up land and spatial allocation of economic activity. The results found in this study prove that the impact of improved accessibility is heterogeneous on the type of infrastructure. For public transportation, the effects of accessibility changes on residential and the overall construction density are negative and statistically significant, of -0,66 and -0,75 percent, respectively. On the other hand, the effect on service, commercial, and industrial purposes is positive but not statistically significant.

On the contrary, private transportation has a positive and significant impact on squared meters built for the sum of all purposes, as well as for residential and industrial land uses, with effects of 1,72, 1,64, and 1,55 percent, respectively. The impact of improved accessibility because of urban highways inaugurations on service and commercial land use is negative and not statistically significant.

Results also show that the effect of one infrastructure on square meters built depends on the changes in the accessibility measure of the other infrastructure. For the overall construction, services, and commercial purposes, the average marginal effects slope is negative, which suggests a crowding-out type of dynamic between accessibility variables. On the other hand, residential and industrial land use purposes have a positive and statistically significant relation, where the effect of one transport infrastructure increases with the growth of the second accessibility index. This positive relation indicates complementary dynamics of improvement in infrastructures on square meters built.

These results are important for a couple of reasons. First, the effects of new subway stations reduce construction density, while most of the literature finds that subway inaugurations increase density and activity outcomes in neighboring areas (Gibbons and Machin, 2005; Ahlfeldt, 2013; Bowes and Ihlanfeldt, 2001). This unexpected result could be an indication of a spatial reallocation of activities in the city, where a reduction of the commuting cost would increase the relative importance of productivity spillovers, shifting residents from the city center to other areas of the city. Undeveloped real state markets, construction regulations, or lagged reactions to extensions of the subway network could also help explain this outcome. Second, results on the interaction of both transport infrastructure provide insight into complementary and substituting dynamic between subways and urban highways that could help urban planners foresight the economies of scale in public investment.

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Appendix

A1 Tables

Table A1: Inauguration Dates of Transport Infrastructure

Highway of Subway Line	**Number of Stations**	**Type of Highway**	**Inaguration**
Line 5	2		31/Mar/04
Line 2	2		08/Sep/04
Line 2	2		22/Dec/04
Line 2	2		25/Nov/05
Line 5	1		30/Nov/05
Line 4	9		30/Nov/05
Line 4	8		30/Nov/05
Autopista Vespucio Norte		Upgrade	04/Jan/06
Line 4	5		02/Mar/06
Vespucio Sur Express		Upgrade	27/Apr/06
Autopista Central		Upgrade	08/May/06
Line 4A	6		16/Aug/06
Line 2	3		21/Dec/06
Costanera Norte		New	04/Oct/07
Autopista Nororiente		New	06/Feb/08
Túnel San Cristóbal		New	03/Jul/08
Line 4	1		05/Nov/09
Line 1	3		07/Jan/10
Line 5	5		12/Jan/10
Autopista Acceso Sur		New	01/Apr/10

Notes: Information from Chile's Concessions and Metro of Santiago archives.

Table A2: Sample Comparison

	Inside Urban Limit	Sample	SII	Distance	Census
Total Square Meters Built	4390,1	4385,7	4162,4		
	(13605,8)	(13587,8)	(13374,7)		
Urban Highways	-1,835	-1,836		2537,8	
	(1,563)	(1,565)		(3614,3)	
Distance to Subway Station in 2010	2,994	3,004		4596,5	
	(3,077)	(3,081)		(6189,8)	
Households in Block	38,82	38,81			38,12
	(54,06)	(54,01)			(56,61)
Population in Block	140,5	140,5			138,4
	(188,5)	(188,4)			(199,4)
Observations	33751	33854	48170	51443	37704

mean coefficients; sd in parentheses

Notes: Own elaboration. Data from Servicio de Impuestos Internos and Census

Table A3: Speeds used in Network Analysis

Mode	Speed ($\frac{km}{h}$)
Urban Highways	60
Private	34
Buses	23
Subway	35
Walking	4

Notes: Informe Final EOD 2001 and 2012 (SECTRA, a,b).

Table A4: Testing for Parallel Trends for housing purposes (1990-1995)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	0,75			-4,42
	(1,47)			(2,84)
$\Delta(\ln(Acc_{Pri}))$		-1,28		-2,37
		(1,52)		(5,23)
$\Delta(\ln(Acc_{Both}))$			-2,50	
			(2,88)	
$\Delta(\ln(Acc_{Pub})) \times \Delta(\ln(Acc_{Pri}))$				11,65
				(18,50)
2001 Acc.(Θ_{2001})	Yes	Yes	Yes	Yes
Distance to SW	Yes	No	Yes	Yes
Distance to UHW	No	Yes	Yes	Yes
Observations	261	407	362	362
R^2	0,0235	0,1047	0,1742	0,4391

Standard errors in parentheses

Notes: Table reports coefficients from Estraus-level regression and robust standard errors (clustered at Estaus level), weighted by the zone's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure and accessibility in 2001. The sample studied are those areas located in the urban limit and within the 2 km buffer for Columns (1) and (2), and of 1,25 km buffer for Columns (3) and (4). Columns (1) and (2) study blocks treated by public and private transportation individually, while Columns (3) and (4) study the effects on blocks treated by either infrastructure.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A5: Testing for Parallel Trends for services and commercial purposes (1990-1995)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	0,15			-0,79
	(1,01)			(0,53)
$\Delta(\ln(Acc_{Pri}))$		1,15		3,76
		(1,39)		(2,63)
$\Delta(\ln(Acc_{Both}))$			-1,48**	
			(0,62)	
$\Delta(\ln(Acc_{Pub})) \times \Delta(\ln(Acc_{Pri}))$				-6,55
				(9,67)
2001 Acc.(Θ_{2001})	Yes	Yes	Yes	Yes
Distance to SW	Yes	No	Yes	Yes
Distance to UHW	No	Yes	Yes	Yes
Observations	261	407	362	362
R^2	0,0378	0,2804	0,2558	0,2750

Standard errors in parentheses

Notes: Table reports coefficients from Estraus-level regression and robust standard errors (clustered at Estaus level), weighted by the zone's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure and accessibility in 2001. The sample studied are those areas located in the urban limit and within the 2 km buffer for Columns (1) and (2), and of 1,25 km buffer for Columns (3) and (4). Columns (1) and (2) study blocks treated by public and private transportation individually, while Columns (3) and (4) study the effects on blocks treated by either infrastructure.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A6: Testing for Parallel Trends for industrial purposes (1990-1995)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	0,86			-5,77**
	(1,15)			(2,84)
$\Delta(\ln(Acc_{Pri}))$		-0,79		-1,93
		(2,01)		(4,79)
$\Delta(\ln(Acc_{Both}))$			-3,18	
			(2,66)	
$\Delta(\ln(Acc_{Pub})) \times \Delta(\ln(Acc_{Pri}))$				10,23
				(18,50)
2001 Acc.(Θ_{2001})	Yes	Yes	Yes	Yes
Distance to SW	Yes	No	Yes	Yes
Distance to UHW	No	Yes	Yes	Yes
Observations	261	407	362	362
R^2	0,0222	0,2640	0,3339	0,4365

Standard errors in parentheses

Notes: Table reports coefficients from Estraus-level regression and robust standard errors (clustered at Estaus level), weighted by the zone's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure and accessibility in 2001. The sample studied are those areas located in the urban limit and within the 2 km buffer for Columns (1) and (2), and of 1,25 km buffer for Columns (3) and (4). Columns (1) and (2) study blocks treated by public and private transportation individually, while Columns (3) and (4) study the effects on blocks treated by either infrastructure.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A7: Public Transportation Results - Effects of accessibility on built-up land (2001-2010)

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pub}))$	0,06	-0,05	-1,12***	-0,96**	-0,75**	-0,75***
	(0,54)	(0,50)	(0,41)	(0,43)	(0,29)	(0,29)
2001 Acc.(Θ_{2001})	No	No	No	Yes	Yes	Yes
Block Controls	No	No	No	No	Yes	Yes
Distance to CBD	No	Yes	Yes	Yes	Yes	Yes
Distance to SW/UHW	No	No	Yes	Yes	Yes	Yes
Initial Level(SMB_{2001})	No	No	No	No	No	Yes
Observations	16147	16147	16147	16147	13175	13175
R^2	0,0001	0,0233	0,0956	0,0985	0,0898	0,0909

Standard errors in parentheses

Notes: Table reports coefficients from block-level regression and robust standard errors (clustered at Estaus level), weighted by the block's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, block baseline characteristics (population density, household socioeconomic information, population and number of households), and initial levels of construction density. The sample studied are those areas located in the urban limit and within the 2 km buffer.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A8: Private Transportation Results - Effects of accessibility on built-up land (2001-2010)

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pri}))$	4,53***	4,06***	2,98***	2,82***	1,72***	1,91***
	(0,93)	(0,85)	(0,82)	(1,05)	(0,48)	(0,53)
2001 Acc.(Θ_{2001})	No	No	No	Yes	Yes	Yes
Block Controls	No	No	No	No	Yes	Yes
Distance to CBD	No	Yes	Yes	Yes	Yes	Yes
Distance to SW/UHW	No	No	Yes	Yes	Yes	Yes
Initial Level(SMB_{2001})	No	No	No	No	No	Yes
Observations	26349	26349	26349	26349	21014	21014
R^2	0,1721	0,2017	0,2344	0,2347	0,1943	0,1958

Standard errors in parentheses

Notes: Table reports coefficients from block-level regression and robust standard errors (clustered at Estaus level), weighted by the block's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, block baseline characteristics (population density, household socioeconomic information, population and number of households), and initial levels of construction density. The sample studied are those areas located in the urban limit and within the 2 km buffer.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A9: Private and Public Transportation Results - Effects of accessibility on built-up land (2001-2010)

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Both}))$	1,11***	0,83***	0,57***	0,44**	0,31	0,35
	(0,23)	(0,22)	(0,21)	(0,22)	(0,24)	(0,35)
2001 Acc.(Θ_{2001})	No	No	No	Yes	Yes	Yes
Block Controls	No	No	No	No	Yes	Yes
Distance to CBD	No	Yes	Yes	Yes	Yes	Yes
Distance to SW/UHW	No	No	Yes	Yes	Yes	Yes
Initial Level(SMB_{2001})	No	No	No	No	No	Yes
Observations	22585	22585	22585	22585	18057	18057
R^2	0,0461	0,0671	0,1111	0,1163	0,1832	0,1839

Standard errors in parentheses

Notes: Table reports coefficients from block-level regression and robust standard errors (clustered at Estaus level), weighted by the block's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, block baseline characteristics (population density, household socioeconomic information, population and number of households), and initial levels of construction density. The sample studied are those areas located in the urban limit and within the 1,25 km buffer.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A10: Private and Public Transportation Results - Effects of accessibility on built-up land (2001-2010)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$	(5) $\Delta(\ln(SMB))$	(6) $\Delta(\ln(SMB))$
$\Delta(\ln(Acc_{Pri}))$	4,16***	4,09***	3,96***	2,58***	2,61***	2,79***
	(1,39)	(1,10)	(0,92)	(0,76)	(0,78)	(0,86)
$\Delta(\ln(Acc_{Pub}))$	0,48**	0,21	0,18	-0,10	-0,16	-0,14
	(0,22)	(0,19)	(0,23)	(0,20)	(0,20)	(0,22)
$\Delta(\ln(Acc_{Pri})) \times \Delta(\ln(Acc_{Pub}))$	-6,37	-5,78	-8,10*	-4,78	-4,45	-4,26
	(4,76)	(3,98)	(4,29)	(3,08)	(2,87)	(3,04)
2001 Acc.(Θ_{2001})	No	No	No	Yes	Yes	Yes
Block Controls	No	No	No	No	Yes	Yes
Distance to CBD	No	Yes	Yes	Yes	Yes	Yes
Distance to SW/UHW	No	No	Yes	Yes	Yes	Yes
Initial Level(SMB_{2001})	No	No	No	No	No	Yes
Observations	22585	22585	22585	22585	18057	18057
R^2	0,0704	0,1017	0,1254	0,1374	0,2077	0,2116

Standard errors in parentheses

Notes: Table reports coefficients from block-level regression and robust standard errors (clustered at Estaus level), weighted by the block's surface area. $\Delta(\ln(SMB))$ denotes the difference in squared meters expressed in logarithm. The variable $\Delta(\ln(\Theta))$ is the change in the measure of the accessibility index. Each column is from a separate regression, controlling for distance to infrastructure (new subway stations and urban highways), accessibility levels in 2001, proximity to the CBD, block baseline characteristics (population density, household socioeconomic information, population and number of households), and initial levels of construction density. The sample studied are those areas located in the urban limit and within the 1,25 km buffer.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$