The spatial-economic dimensions of commuting in Santiago, Chile

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Abstract

Many studies in Europe and the United States have found urban form to significantly influence travel behavior. These finding suggest that urban planning policies can indirectly reduce emissions caused by transportation. These types of policies could be relevant in a developing world context where motorization is increasing at vertiginous rates. Nonetheless, little empirical evidence exists for cities in Latin America that are characterized by high levels of density, high levels of congestion and few urban development regulations. Using data from a large travel survey conducted in the sprawling metropolis of Santiago, Chile, the impact of urban form (density, diversity, design, destination accessibility and distance to transit) as well as average household income on commuting patterns is examined. The results show that at a neighborhood level, urban form has less of an influence on commuting patterns than found in previous studies on North American and European cities. Instead, neighborhood average household income, as well as distance from the center are the most important determinants of commuting patterns. The city's wealthiest neighborhoods enjoy the shortest and quickest commute times, yet increasingly do so by private vehicle. Due to the monocentricity of Santiago, those neighborhoods farthest away from the center, which are also the poorest, have the longest and farthest commutes. As the economy of Chile continues to grow along with the size of Santiago, steering travel behavior away from the private vehicle as well as creating job centers in areas closer to the periphery will be key components of urban sustainability policy.

1. Introduction

Many cities in the developing world suffer from high levels of air pollution that pose a serious risk to public health. In fact, according to the World Health Organization (WHO), 97% of cities in developing countries do not meet WHO air quality guidelines (WHO, 2018). In Latin America, the most urbanized region of the developing world, with over 79% of its population living in urbanized centers, this amounts to millions of people exposed to harmful pollutants every single day (Riojas-Rodríguez, Soares Da Silva, Luis Texcalac-Sangrador, & Litai Moreno-Banda, 2016).

One of the largest contributors to greenhouse gases in cities around the world, and in Latin America in particular, is the transportation sector (IEA, 2016; Karagulian et al., 2015). Without stricter emissions standards and/or significant investments in public transport, car use in the region is expected to grow by 300% by 2030 (Mcandrews, Deakin, & Schipper, 2010; Schipper, Deakin, Mcandrews, Scholl, & Frick, 2009). Since light duty vehicles[1] generate most of the emissions in Latin American metropolitan areas, managing their use will be an important component of strategies to reduce emissions in cities.

Increase in car sales in Latin America from Q1- 2017 to Q1-2018. JATO, 2018

[1] Light duty vehicles are parts of a vehicle fleet that include private cars, SUV's and light trucks.

The well-researched relationship between transportation and the built environment (Borrego et al., 2006; Ewing & Cervero, 2010a) suggests that changes in the urban structure of a city can help support these mitigation efforts. Metrics of urban form have been found to affect Vehicle Kilometers Travelled (VKT), mode choice, travel time, travel length and travel frequency (Barrett, 1996; Cervero, 1996). Therefore, policies that influence land-use patterns, urban densities and designs, can significantly shape travel behavior and thus emissions from travel (Ewing & Cervero, 2010b; Glaeser & Kahn, 2003; Stone, 2008).

Commuting is an important element of travel behavior that has a unique relationship to urban form. Due to its regular patterns, its effects on congestion, and its relationship to the selection of workplaces and residence, it is a key component of transport and urban planning policy (Garcia-Sierra, Miralles-Guasch, Martínez-Melo, & Marquet, 2018; Lin, Allan, & Cui, 2016; Van De Coevering & Schwanen, 2005).

Previous studies in North America and Europe have shown that cities with higher densities of people and dwellings as well as those with a greater mixing of land-uses, reduce trip lengths and number of motorized commuting trips by concentrating residential, employment and service areas (Cervero & Kockelman, 1997; Ewing & Cervero, 2010b). In addition, the urban structure of development, be it polycentric with several clusters of commercial activity or monocentric with concentrated development in one main center have significant effects on commuting patterns (Gordon, Kumar, & Richardson, 1989a; Levinson & Kumar, 1994). Nonetheless, empirical evidence for developing countries is limited (Gainza & Livert, 2013; Motte, Aguilera, Bonin, & Nassi, 2016; Zupancic, Research, & Westmacott, 2015). The mechanisms through which urban form affects commuting patterns could very well be different in Latin America and other developing countries than in developed regions.

In addition, previous research has found that there exists more than just physical factors that affect travel behavior. Socioeconomic factors such as urban history, culture, the economy, and institutions as well as individual factors like socio-economic characteristics and preferences can all affect patterns in transportation (Lin et al., 2016). Some studies even suggest that in the case of commuting patterns, these "soft" factors are more influential than physical environment characteristics (D. Stead, 2001; Van De Coevering & Schwanen, 2005). In Latin America urban growth and transportation are very much influenced by socioeconomics, characterized by high levels of residential segregation and congestion as well as the informality of the public transportation sector (Gainza & Livert, 2013; Lankao, 2007; Riojas-Rodríguez et al., 2007). Thus when looking at factors that affect travel behavior, incorporating both variables related to physical structure as well as socioeconomics into the research is essential for finding meaningful associations in a developing world context.

This paper examines commuting patterns in Santiago, Chile. Santiago exhibits various characteristics that set it apart from cities in the developed world. First, over the past few decades the city structure of Santiago has changed dramatically with few urban development restrictions to accommodate a growing population as well as a rapidly developing economy (Gainza & Livert, 2013; Rodríguez & Winchester, 2001). Weak urban development restrictions are typical of a Latin American city but not so common in North America and Europe where land use is tightly controlled (Lungo, 2001). Second, urban density in Santiago, Chile (5600 inhabitants/km^2) is much greater than the average population densities in North America and Europe (1600 and 3100 inhabitants/km^2) (Demographia, 2018) which leads to uncertainty of the effects of greater densification. Third, Chile, has had a different urban growth trajectory than most cities in North America and Europe. Growth in the periphery of urban areas has not always been of low density developments, but is oftentimes characterized by high density, low-income informal settlements (Gainza & Livert, 2013; Lungo, 2001). Fourth, use of public transportation is relatively high in Chile, compared to, for example, North America, yet the motorization rate is growing rapidly, adding more cars to the road (Gainza & Livert, 2013; Zegras, 2010). And finally, inequality in Chile is much higher than in developed countries and great disparities exist between neighborhoods making socio-economic factors potentially quite influential for commuting patterns (Gainza & Livert, 2013; Rodríguez & Winchester, 2001).

The aim of this research will be to uncover the spatial and economic dimensions of commuting patterns in Santiago, Chile by looking at built environment and socioeconomic characteristics of different neighborhoods. This study will use the most recent Santiago Origin-

Destination travel survey to look at neighborhood level characteristics that could motivate certain mode choices as well as commute distances and times. In a highly segregated city such as Santiago, differences among neighborhoods like income, population and transit density as well as distance to the center are likely to predict certain commuting behaviors. This research is, thus, a first step towards better understanding the impact of urban form characteristics on commuting patterns at a neighborhood scale in Chile.

This paper is organized as follows: section 2 discusses the existing literature on urban form and commuting behavior in general and then in the Santiago-specific context. Section 3 is dedicated to explaining the data and methodology while section 4 contains the results obtained. Finally, section 5 discusses the implications of the findings and concludes.

2. Literature Review

Commuting patterns can be influenced by physical characteristics of the environment, like urban density and street design, as well as by socio-economic factors at the city level, like history and economics, and at the individual level, like income, education and age (Lin et al., 2016). While most studies look at either intra-city or individual level variation in commuting patterns, few have researched the connection within neighborhoods in cities (Crane & Crepeau, 1998). Furthermore, even fewer have done so for cities in the developing world (Gainza & Livert, 2013; Motte et al., 2016; Punpuing, 1993). When looking at intra-city commuting patterns, city level socio-economic characteristics are constant across space, yet the physical and individual level factors remain heterogeneous. Studies that have looked at differences in commuting patterns between neighborhoods often fail to incorporate both the spatial and social factors into their analysis (Cervero & Gorham, 1995). Income in particular is a confounding influence often overlooked.

The focus of this study will be to look at the urban form as well as socio-economic characteristics of neighborhoods in Santiago. There is much disparity between these neighborhoods both in terms of urban form and socioeconomically (Gainza & Livert, 2013; Rodríguez & Winchester, 2001). This study will thus highlight how commuting patterns can change in a city of homogenous institutions and perceived economic development but with a large diversity of urban morphology and socio-economic spatial patterns.

2.1 Urban form and commuting

The effect that urban form has on travel behavior is a research topic academics have been attempting to tackle for years (Bento, Cropper, Mobarak, & Vinha, 2005; Boarnet & Sarmiento, 1998; Crane, 2000; Gordon et al., 1989a; Khattak & Rodriguez, 2005; Krizek, 2003; Lin et al., 2016; Schwanen, Dijst, & Dieleman, 2004; D. S. J. Stead, London, & Stead, 1999). City structure can influence the time spent traveling, the distances travelled and the transportation mode used. Therefore, how certain activities, like work, are organized in space is important to understand in order to minimize the energy use and emissions caused by travel. A principal dichotomy exists between the sprawling city that has been shown to increase the length of trips and encourage the use of private vehicles, and the densely populated, polycentric urban areas where mixed land use increases the profitability of public transport and shortens trip distances (Frank, Pivo, & Frank, 1994; Glaeser & Kahn, 2003).

For the purposes of this research, the meta-analysis of Ewing and Cervero (2010) on Travel and the Built Environment will be used as a conceptual model. In this paper, the authors define essential built environment characteristics that affect travel. They are named the "five D's" - density, diversity, design, destination accessibility and distance to transit. In addition to the five D's, a socioeconomic factor of average income per household will be incorporated because of its robust effects on mode choice, and commute distances and times (Gainza & Livert, 2013; Lin et al., 2016; Shen, 2000; Sun, Ermagun, & Dan, 2017)

Density

Past research has found different effects of density on mode choice and distance and travel time of commutes. The important work of Newman and Kenworthy (1989) that looked at several cities around the world found that density is the main determinant of commute times. Furthermore, although fuel efficiency is lower in dense areas because of congestion, Ewing (2008) found that people drive substantially less in these dense areas leading to less fuel consumption per capita. However, Ewing and Cervero (2010) found that after controlling for the other *D's*, density, particularly job and population densities, is only weakly associated with travel behavior. In the case of Santiago, Gainza and Livert (2013) found that residential density does, however, slightly induce commuters to use more public transportation.

Diversity

Land-use mix is assumed to reduce car dependence, and travel distances and times, because relevant destinations for travelers can be in closer proximity to each other. A study by Frank and Pivo (1994) using a longitudinal data set from the Puget Sound region in the Northwest United States found that higher land-use mix at both the origin and destination of commuting trips increased the use of public transportation. Cervero and Duncan (2006) found that when land-use mix allows for jobs and residential areas to be in closer proximity, commute times and distances are greatly reduced. However, there are a few cases where this relationship is weaker than expected because of factors that affect residential choice (Gainza & Livert, 2013; Giuliano & Small, 1993; Miller & Ibrahim, 1998). People can choose to locate in places because of other non-work amenities available there or they can have difficulties in finding a central location in two-worker households (Gainza & Livert, 2013; Giuliano & Small, 1993). In the case of Santiago, Gainza and Livert (2013) found that land-use diversity is positively and significantly correlated with use of public transport.

Design

Design has significant effects on mode choice, with more gridded type street networks having a positive correlation with public transport use for commuting (Cervero & Gorham, 1995). In addition, neighborhoods that are more conducive to transit also exhibit higher shares of walking and biking trips (Cervero & Gorham, 1995). In a developing world context, Sun et al (2017) found that in Shanghai, more four way intersections were negatively associated with the probability of commuting with a private vehicle. A more dense road network could potentially reduce the costs of traveling by automobile as well as travel times and distances. Vance and Hedel (2007) found that in fact, it does reduce miles traveled by vehicle for work travel. More roads indicate a higher degree of connectivity (Ewing & Cervero, 2010b).

Destination accessibility

Destination accessibility measures the ease of access to trip destinations (Ewing & Cervero, 2010b). It can be closely related to the structure of the city and whether it is more polycentric or monocentric, making important destinations like jobs more likely to be farther (or closer). In cities that grow rapidly, a polycentric design, that allows for several different concentrations of employment around the city, can help curb commuting distances (Zhao, Lu, & de Roo, 2011). In fact, sprawling cities that decentralize employment can lead to lower emissions generated by commuting trips if congestion is reduced on these more varied routes (Glaeser & Kahn, 2003).

Distance to transit

It is not a surprise that distance to transit is positively associated with public transit mode choice for travel trips and commuting (Ewing & Cervero, 2010b). Public transit density was used in a study looking at the impact of transit access in Portland and results showed that higher public transit density increases public transportation use (Ewing, R. et al., 2009). Being closer to a transit stop or living in an area with a richer network of public transportation has also been linked to more walking trips and less use of private vehicles (Ewing & Cervero, 2010a). In Santiago, certain neighborhoods, more often those farther away from the center and with lower average incomes, have fewer transportation options available.

Socio-economic factors

Studies on the relationship between the built environment and commuting have increasingly looked at the effect that social factors have on these patterns (Gainza & Livert, 2013; Lin et al., 2016; Shen, 2000). Shen et al (2000, pg.1) emphasizes that looking solely at differences in neighborhood types, "researchers are likely to overlook the situations of the more disadvantaged population groups, who are supposedly the main target of policies and programs to improve access to jobs". Race, gender, age and education can all influence commuting patterns. Minorities in the US have been found to have longer commute times (Shen, 2000). Women have been found to have shorter commute times than men, in part due to the traditional division of household responsibilities. Women who are responsible for most household duties tend to choose a place of work closer to home in order to economize their time (Schwanen, Dieleman, & Dijst, 2003; Turner & Niemeier, 1997). Middle-aged commuters have been found to have longer commutes than their younger and older counterparts (Levinson, 1998). Education has a strong relationship with commuting distance and time. Higher educated individuals tend to have longer and farther commutes (Green, Hogarth & Shackleton, 1999; Rouwendal & Rietveld, 1994; Schwanen, Dieleman, & Dijst, 2001; Schwanen et al., 2003; Turner & Niemeier, 1997).

Income, both at the individual and at the neighborhood level, is often a confounding factor that influences travel behavior (Cervero & Gorham, 1995). Higher incomes have been linked to both farther and shorter travel distances (Gordon, Kumar, & Richardson, 1989b; Turner & Niemeier, 1997). In some cases, higher incomes can lead to a greater ability to select housing near workplaces, yet those with higher incomes tend to have more specialized jobs that can be farther away from typical job centers (Cervero & Kockelman, 1997; Shen, 2000). At the neighborhood level, Cervero (1995) found that higher levels of household income led to significantly less use of public transit for commutes. In the case of Santiago, income is closely related to motorization and therefore higher incomes have been found to be more closely associated with more vehicle use (Gainza & Livert, 2013; Riojas-Rodríguez et al. 2005.; Zegras, 2010).

2.2 The context of Santiago, Chile

Much like the rest of Latin America, Santiago, Chile developed rapidly over the past sixty years growing from 11,017 ha in 1940 to 64,140 ha in 2002 (Galetovic & Jordán, 2006). This rapid growth was due in part to the state housing policy, an extensive program that is estimated to have built between one half and one third of all homes from the 1950's to the 2000's (Tokman, 2006). These public housing developments were mostly located in the periphery due to the low cost of land and larger plot sizes available, further extending the urbanized area (Ducci, 1997; Hidalgo Dattwyler, 2007). A policy from the military dictatorship in the late 1970's that greatly increased the urban growth boundary to 100,000 ha from a built up area of just 35,000 ha is also seen as an important driver of the sprawl witnessed today. At the time, the government believed market forces would contain sprawl so there was no need to restrict city growth limits (Gainza & Livert, 2013).

While Santiago has grown extensively, it is still very monocentric with 40% of commuting trips ending in the CBD (Rodriguez Vignoli, 2008; SECTRA, 2014). See figure 2 below. This is consistent with trends of most cities that have been sprawling but maintain the greatest concentration of workplaces, retail centers and public agencies in the historic center (Fernández-Maldonado, Romein, Verkoren, & Parente Paula Pessoa, 2014; Naess, 2012; Sun et al., 2017)

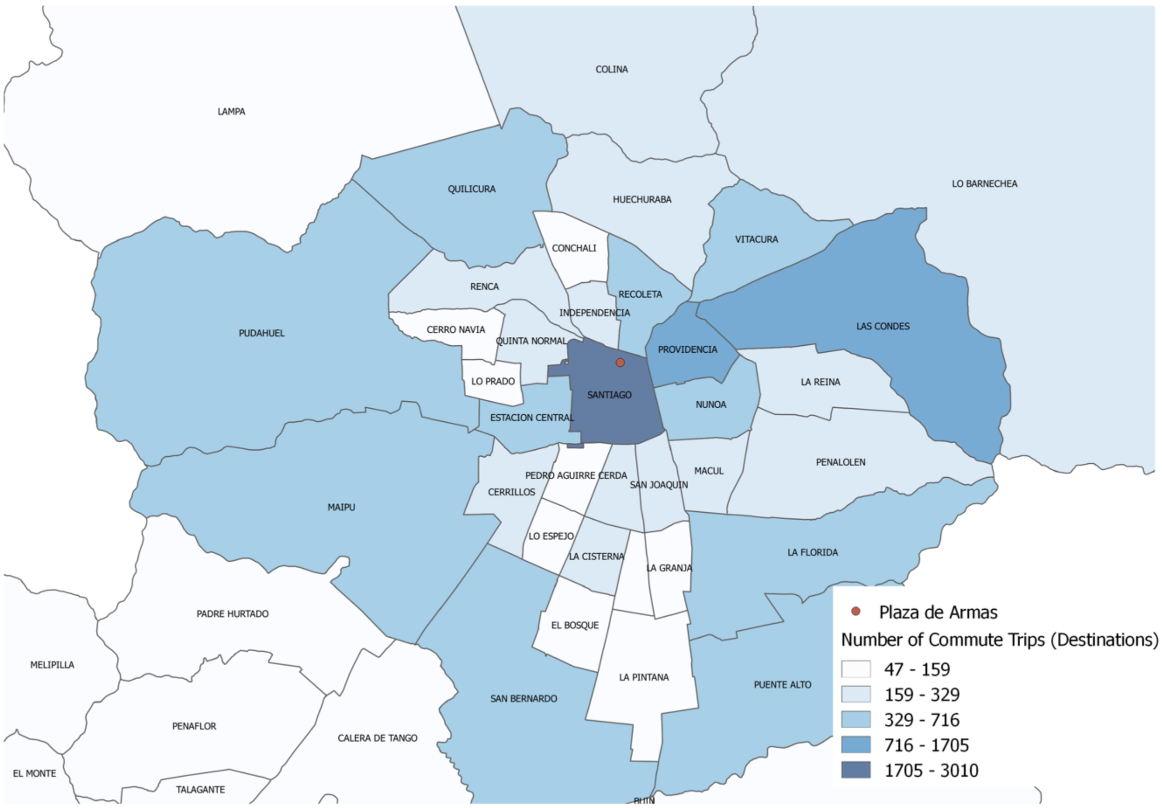


Figure 1. Number of commuting trip destinations per commune. Generated by author in QGIS.

Santiago is also segregated economically, something that the urban growth pattern has reinforced. While the poorest households are forced to the urban fringe, where they are provided housing, the northeastern foothills of the city house the richest families (Gainza & Livert, 2013; Riojas-Rodríguez et al., 2007). Furthermore, this segregation dictates the commuting flows in that commuters in these poorer communes travel to the richest communes. The 6 richest communes attract about 30% of commuting trips, while the 6 poorest communes attract only 4% of commuting trips (SECTRA, 2014).

2.2.1 Urban transportation challenges in Santiago

Implications of this economic segregation can also be observed in the city's motorization rates. Latin America has the fastest growing motorization rate in the world at a 4.5% increase of number of passenger cars per 1,000 inhabitants per year. In Santiago motorization grew from 90 motor vehicles per 1000 residents in 1991 to 205 motor vehicles per 1000 residents in 2015 (MTT, 2013). However, in the richest communes of Santiago, motorization rates are fifteen times higher than in poor communes (Gainza & Livert, 2013).

Nonetheless, public transport is still the most widely used mode of travel in the city. Latin America as a whole has the world's highest per capita bus use (UNEP, 2017; World Bank, 2013). In many cities in the region, on a typical workday half of all passenger trips are completed using public transportation (e.g. 70% in Mexico City and Panama City). In Santiago around 35% of trips are completed using public transportation (SECTRA, 2014).

In 2007, Santiago implemented its own Bus Rapid Transit system dubbed "Transantiago". This fully integrated public transport system covers the whole Metropolitan area of Santiago and is comprised of a privately operated bus service and a state-owned metro system. It was meant to replace all existing bus public transport. The existing system was perceived to be too unorganized, too inefficient and too expensive. In fact, switching from the bus to the metro in one trip was too expensive for most users (Figueroa, 2013). However, when this new system was implemented in February, 2007, the infrastructure and conditions necessary for its operation were not in place (Muñoz, Batarce, & Hidalgo, 2014). This new, incomplete system put into operation overnight, could not cope with the demand leading to an extremely chaotic roll out. In Chile some consider Transantiago "the worst public policy ever implemented in the country" (Muñoz et al., 2014). Nowadays, Transantiago has improved substantially and although it still has improvements to undertake, its benefits include promoting the use of planning principles into transport, eliminating redundancies in the transport network and improving the quality and environmental standards of buses. In particular, the simplified payment scheme with the single-fare system has been shown to increase use of the metro, especially by low-income users (Pardo Díaz & Pedrosa, 2012).

3. Data and Empirical Methodology

3.1 Santiago Origin-Destination Travel Survey

The data for commuting time, mode and distance was taken from an Origin-Destination Travel survey that was carried out for households in the Metropolitan Region of Santiago (SECTRA, 2014). The survey had two main objectives: first, to collect detailed information about trips that are completed in Santiago and the people that make them. Second, to collect the required information needed for developing strategic transportation models for the city. The survey contains information on transport patterns of representative trips from households and individuals, including details on the origin, destination, distance and duration of trips taken, description of transport mode used as well as information on the household. These data on current transport patterns in Santiago provide a basis for modelling future developments in urban transport including the impact of possible policy interventions.

The collection of the data was completed at two different time points, one during the school year and one during the summer, while also taking into account the differences between normal working days and weekends. It was carried out between July 2012 and November 2013. The study area was comprised of 45 communes in Santiago, of which there are 52 total. At the time of the study this area housed approximately 6.5 million people with an estimated 1.16 million private use vehicles, 6,300 buses, 27,000 taxis, 11,000 shared-ride taxis (taxis that operate similar to buses in that they have fixed or semi-fixed routes but are smaller and privately run), and 5 metro lines with 104 km of tracks. In total 18,000 households were surveyed constituting about 60,000 people (SECTRA, 2014).

3.2 Commuting distance, time and mode choice

For the purpose of the thesis, only commuting trips from the survey were used which amounted to 17,257 trips. For each of the communes, average commuting time, commuting distance and percentage of commutes with private transport were calculated. Statistics about population and household income by commune were taken from the survey. Commune surface areas were calculated using QGIS.

The average commute time for the communes was 51.9 minutes, with the longest commute time being 75.3 minutes from La Pintana in the South Eastern part of the city and the shortest average commute time being 30.2 minutes from Providencia a commune in the center of the city. The average commute distance for all communes was 9.65 kilometers, with the longest commute distance (19.6km) being from El Monte, a commune in the south west part of the city outside of the main city ring, and the shortest average commute distance being 3.3 km, also from Providencia.

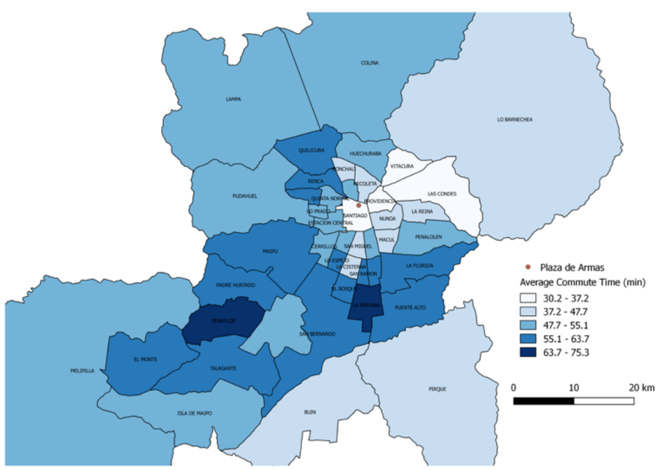


Figure 2. Average commute times per commune. Generated by author in QGIS.

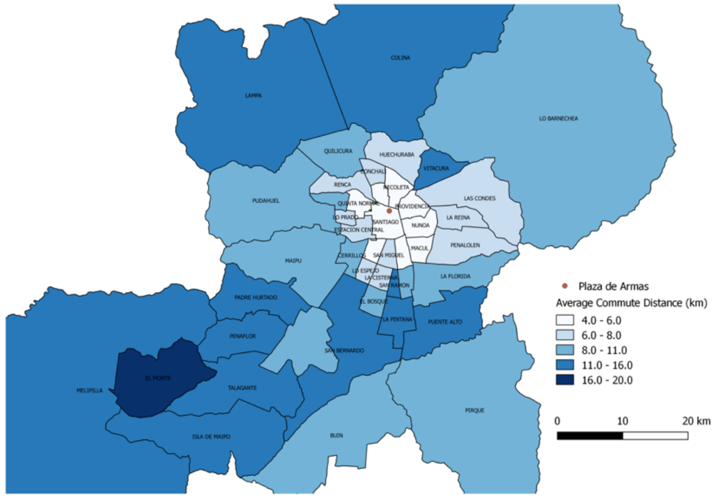


Figure 3. Average commute distance per commune. Generated by author in QGIS.

The commune with the highest average percent of commutes by private transport is Lo Barnechea in the Northeast (72.6%), while the commune with the lowest share of trips by private transport is La Pintana (8.96%). The average modal split for all communes is 28.6% of trips taken using private transport.

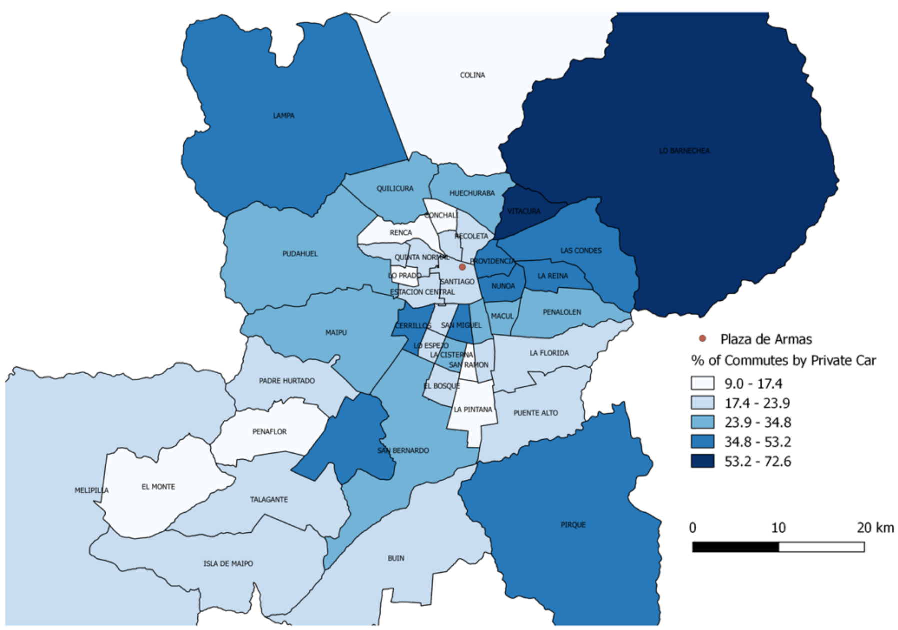
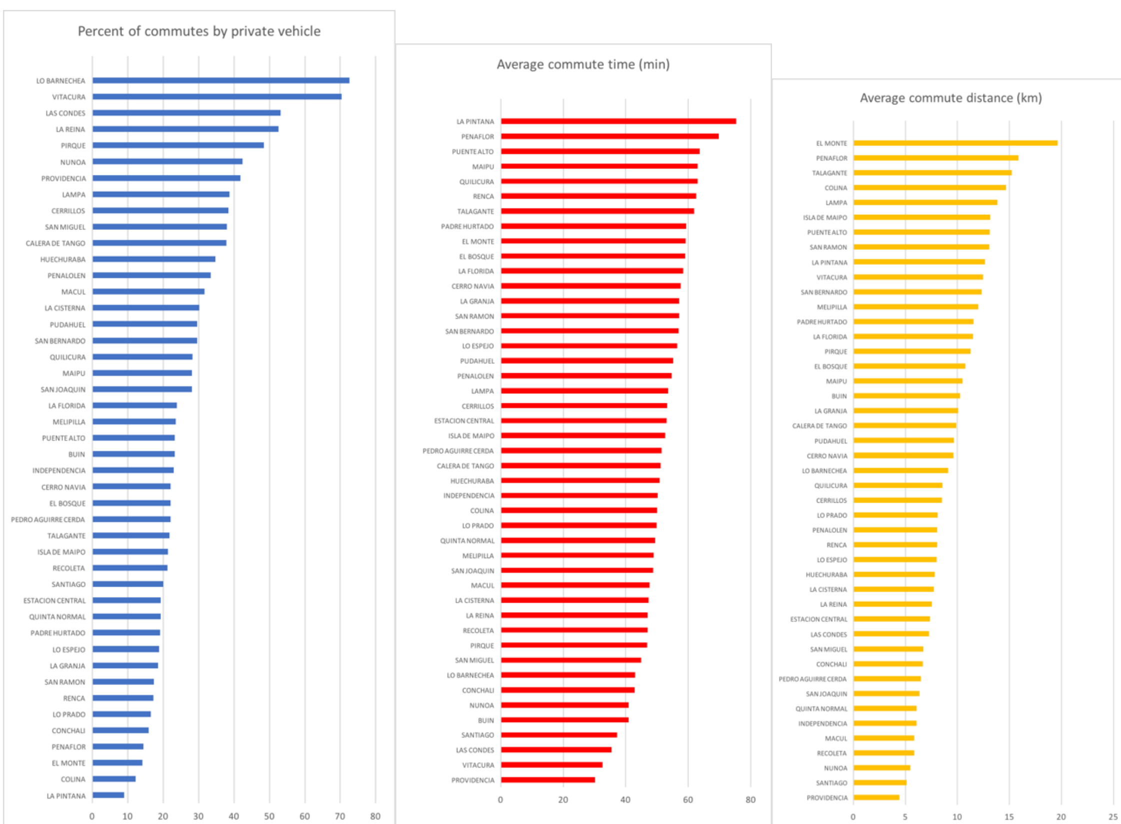


Figure 4. Percent of commutes by private car per commune. Generated by author in QGIS.

The average commute time is quite long in comparison to most cities around the world despite similar average commuting distances. In European cities, the average commute takes 28 minutes and is on average 10 kilometers long (Schwanen, 2002), which is similar to the average commute distance of Santiago. In the US, the average commuting time is 26.1 minutes (US Census, 2015) while the average commuting distance is 12.5 kilometers (Kneebone & Holmes, 2015).

Exorbitantly long commute times are common in Latin America mostly due to congestion (Lopez-Ghio, Bocarejo, & Blanco Blanco, 2018; Van Mead, 2017). Traffic jams are common in Santiago and they seem to be getting worse. Between 2001 and 2012, travel times for trips of similar length rose by 20% (SECTRA, 2014). Policy makers are considering implementing congestion charges that would charge vehicles entering the center of the city at peak times in order to relieve this issue.



The variation in mode choice, travel time and distance is large between the communes. Mode choice has a coefficient of variation (which shows how much the variable varies in relation to its mean - the higher the coefficient the greater the dispersion of the variable) of 48.9. Whereas travel time has a coefficient of variation of 17.8 and travel distance 34.3. It makes sense that the coefficient of variation for distance would be greater than that for time since the time that people are willing to spend commuting is more constant across space than the distances they are willing to commute (Marchetti, 1994). As many cities have grown, commuting distances have increased yet times have remained relatively constant (Angel & Blei, 2016; Marchetti, 1994). Nonetheless, this doesn't seem to be the case for everyone in Santiago where congestion and sprawl have lengthened commute times considerably (Herrera & Razmilic, 2016).

3.3 Urban form metrics

Following the model of the 5 D's, metrics for each D were collected. *Density* is the most widely used urban form metric in studies on the built environment and commuting (Ewing & Cervero, 2010). However, there are several ways to measure density. It can be population, dwelling units, employment, building floor area density etc. For this study both dwelling and population density measures were calculated using Chilean census data (Censo, 2017), but only dwelling density ended up in the final models because of its more robust effects and because of its use in previous studies on Santiago (Gainza & Livert, 2013; C. Zegras, 2010; P. C. Zegras & Hannan, 2012).

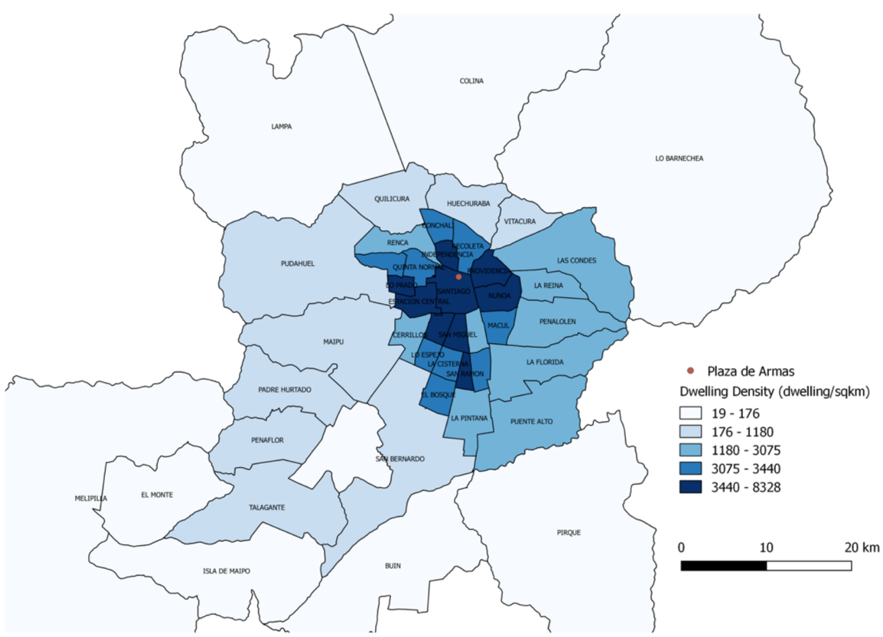


Figure 5. Dwelling density per commune. Generated by author in QGIS.

Land-use *diversity* is also widely used in travel behavior studies. The most common measures to use are based on entropy levels where low values pertain to single-use environments and higher values to mixed-use areas. This index is taken from physics where it is used to measure the uniformity of gaseous mixtures (Kockelman, 1997). Entropy is expressed as:

$$\sum_j \times P_j \frac{\ln{(p_j)}}{\ln{(j)}}$$

where P_j = the proportion of total land area of jth land-use category found in the tract being analyzed and j= total land uses considered in the study area (Kockelman, 1997). It is used to characterize the *balance* of land uses and is most useful when looking comparing across many zones like neighborhoods (Miller & Ibrahim, 1998). It was first used by Cervero (1989) when looking at suburban employment centers and was subsequently used by Frank and Pivo (1994) when looking at census tracts in Seattle.

Another index used by researchers to determine to what extent land-uses are not only balanced but also spatially mixed is the Dissimilarity Index (Kockelman, 1997). It quantifies to what extent land-uses come into contact with one another. Similar to that index are other indices that measure the probability that two random locations in a given area have different uses. This probability is often referred to as the Simpson index, whose inverse is equal to the Herfindahl index that is used in economics to measure whether a market is in perfect competition or closer to a monopoly (Baumgärtner, 2005; Ritsema van Eck & Koomen, 2008). Less frequently, jobs-to-housing or jobs-to-population values are used to measure urban (Ewing & Cervero, 2010b).

When looking at land-uses both diversity and entropy measures give similar results (Ritsema van Eck & Koomen, 2008). For the purposes of this study, the entropy measure was used. To construct the entropy index for Santiago, land-use data from OpenStreetMap (OSM) was used (Geofabrik, 2018). Geofabrik is a company that updates OpenStreetMap maps daily and includes data on road networks, and public transportation stops and routes. The different land-use types from the OSM data were combined into 5 categories: residential, public administration, retail and commercial, industrial and urban green space.

For *design*, or the street network characteristic metric of the commune, road network density per commune was calculated using QGIS and OpenStreetMap road network layers. Street networks can vary from highly gridded to "sparse suburban networks of curving streets forming loops and lollipops" (Ewing & Cervero, 2010). Other measures of street network design include average block size, number of intersections per square mile, sidewalk coverage, average street widths, numbers of pedestrian crossings or any other built environment variables that can show how pedestrian vs. automobile friendly an area is (Ewing & Cervero, 2010). Road network density was chosen to highlight the street connectivity of each commune.

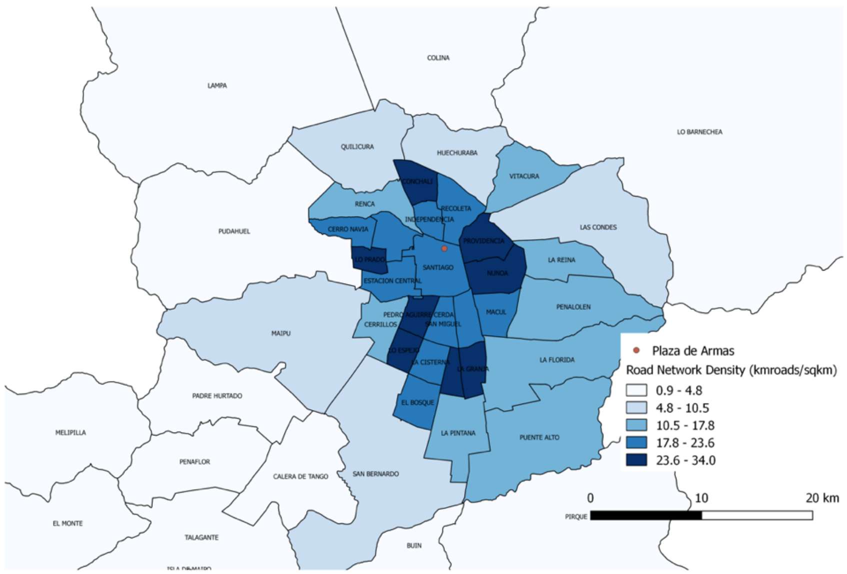


Figure 6. Road network density by commune. Generated by author in QGIS.

For *destination accessibility*, a measure of access to trip destination, the distance to the central business district was used because it is most used in intra-city or within regions accessibility studies (Cheslow & Neels, 1980; Miller & Ibrahim, 1998; C. Zegras, 2010). Furthermore, in cities with a monocentric city structure, where most work trips end in the center, as is the case for Santiago, the distance to the CBD can be one of the most influential factors explaining commuting patterns (Gainza & Livert, 2013; Miller & Ibrahim, 1998; C. Zegras, 2010). In other studies, number of jobs or certain attractions reachable within a given travel time as well as population centrality are used to measure destination accessibility (Bento et al., 2005; Ewing & Cervero, 2010b; Handy, 1996; Lund, Planning, Cervero, & Willson, 2004). The Plaza de Armas, the main square in the center of Santiago, was used as the city center point and distances from there to the centroid of each commune were calculated using QGIS.

For *distance to transit*, public transportation network density was derived using OpenStreetMap transportation network data. For each commune the length of public transportation network was calculated and then divided by its area. Distance to transit measures can also be measured as the average shortest distance from a residence or workplace to the nearest metro or bus stop, the distance between transit stops, or the number of stations per unit area. They are oftentimes used when looking at mode choice patterns in commuting (Ewing & Cervero, 2010b).

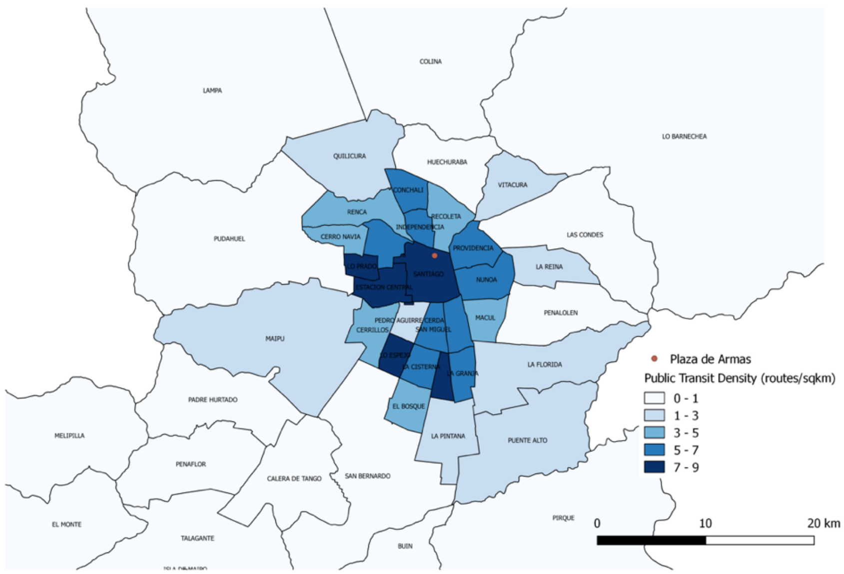


Figure 7. Public transit network density by commune. Generated by author in QGIS.

3.4 Socio-economic metrics

The main socioeconomic variable used in the final regression was average household income per commune. Since the respondents were randomly sampled this value was calculated using household data from the travel survey following the methods of Zegras (2010) and Gainza and Livert (2013). Average household education was calculated, yet it was left out of the model because it was highly correlated with household income. Since this study attempts to uncover relationships at the neighborhood level, individual level characteristics like age and gender were not considered.

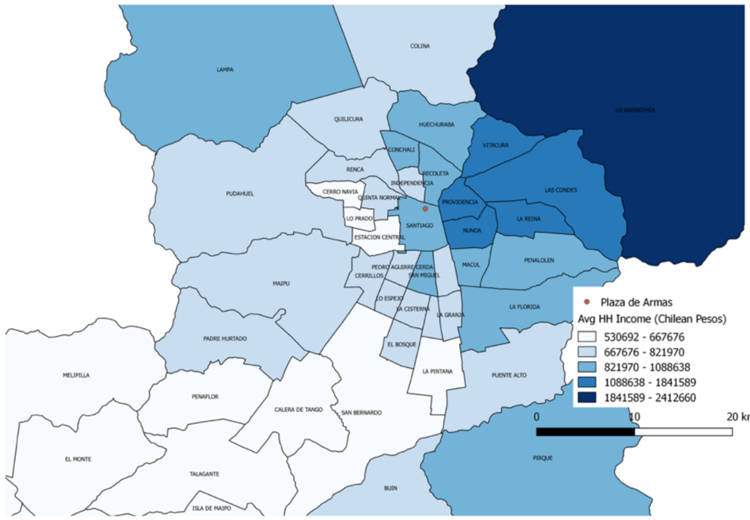


Figure 8. Average household income per commune. Generated by author in QGIS.

3.5 Regression analysis

The effect of the different urban form variables on commuting time and distance was tested using ordinary least squares (OLS) following the work by Engelfriet and Koomen (2017). Furthermore, following the methodology of Shen (2000) on the Spatial and Social dimensions of Commuting, three different models were run. The first model included only income to observe solely the socioeconomic effects on commuting patterns. The second model included only the built environment variables. The third model combined all variables to reveal the combined spatial and social dimensions of commuting. All regressions were run using the statistics software package STATA (StataCorp, 2015).

4. Results

4.1 Urban form, income and mode choice

Table 1 presents the results of the regression of urban form metrics as well as average household income at the commune level on mode choice for commuters in Santiago. In the first model we see that income has a significant positive correlation with private vehicle use for commuting meaning communes with higher average incomes commute more by car. In the second model, dwelling density and distance to CBD have negative correlations with private vehicle use for commuting while transit density and road network density are positively correlated with it. The direction of the effect of dwelling density is consistent with other research on mode choice (Ewing & Cervero, 2010). However, it is quite interesting that those living in communes farther away from the CBD are more likely to take public transit to work while those living in communes with higher transit and road densities are more likely to drive. In the third model, after controlling for income, we see that only transit density maintains its significant effect. Although it is a small effect, it could mean that areas with better transport are more congested, thus commuters are more inclined to drive there to save time.

Average household income in the commune can be observed as the main influence of commute mode choice. People living in richer communes are more likely to commute by private vehicle. This is consistent with other studies carried out in Santiago (Gainza & Livert, 2013; Zegras, 2010) and highlights the importance of the income and motorization issue. If the economic growth in Chile continues and households become richer, it is possible that more and more people will purchase cars to drive to work instead of taking greener modes like non-motorized transport or public transportation.

Table 1. Regression of urban form and income on percent of commutes completed by private vehicle.

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3
Ln Dwelling Density		-0.759***	-0.397**
		(0.225)	(0.164)
Entropy (0-1)		-0.398	0.175
		(0.516)	(0.375)
Ln Road Density		0.676**	0.301
		(0.285)	(0.225)
Ln Dist. to CBD		-0.359***	-0.103
		(0.128)	(0.0942)
Ln Transit Density		0.113*	0.0932**
		(0.0559)	(0.0434)
Ln Income	0.962***		0.899***
	(0.0886)		(0.0942)
Constant	-9.870***	7.936***	-6.778***
	(1.231)	(1.281)	(1.812)
Observations	45	45	45
R-squared	0.578	0.284	0.694

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.2 Urban form, income and commute distance

Table 2 presents the results of the regression of urban form metrics as well as average household income at the commune level on commute distance for commuters in Santiago. In the first model we see that those commuting from richer communes commute significantly shorter distances. In the second model, it can be observed that only distance to the CBD has a significant effect on commute distance. After controlling for income in the third model, both distance to CBD and income remain as significant effects on commute distance. A 1% increase in distance to the CBD of a commune results in a 0.5% increase in average commute distance from that commune. This finding is supported by the literature (Gainza & Livert, 2013; Zegras, 2010) and makes sense due to the monocentricity of Santiago and the fact that most commuting trips end in or around the CBD. Income has less of an effect, albeit a significant one. Richer communes consistently have shorter commutes. While in other cities this is not always the case (Schwanen, 2002; Shen, 2000), in Santiago, the richest communes are also where most people commute to, and tend to be more well connected (SECTRA, 2014; Gainza & Livert, 2013), this could explain the shorter commuting times. It is interesting to note that none of the density metrics nor land use mix have an effect on commuting distance. These bastions of urban form seem to have little influence on commuting distance in Santiago despite their importance in other studies (Engelfriet

& Koomen, 2017; Ewing, Pendall, & Chen, 2002). Although this is an important finding, part of this lack of effect could be due to the fact that the characteristics of the origin of the commute trip are taken into account and not those of the destination.

Table 2. Regression of urban form and income on commute distance (km).

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3
Ln Dwelling Density		0.0999 (0.126)	0.0339 (0.124)
Entropy (0-1)		0.0299 (0.209)	-0.0746 (0.199)
Ln Road Density		-0.0275 (0.186)	0.0408 (0.190)
Ln Dist. to CBD		0.498*** (0.0665)	0.451*** (0.0606)
Ln Transit Density		-0.00594 (0.0219)	-0.00233 (0.0204)
Ln Income	-0.346** (0.148)		-0.164* (0.0887)
Constant	13.83*** (2.012)	7.233*** (0.574)	9.916*** (1.212)
Observations	45	45	45
R-squared	0.129	0.750	0.773

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.3 Urban form, income and commute time

Table 3 presents the results of the regression of urban form metrics as well as average household income at the commune level on commute time for commuters in Santiago. In the first model, it can be observed that communes with higher average income households have on average significantly lower commute times. In the second model, it can be observed that higher levels of dwelling density and entropy as well as being farther away from the CBD increases commute times. After controlling for income in the third model, it can be observed that entropy and distance to CBD maintain their significant and positive effect on commute times while income maintains its significant and negative effect. It makes sense that people living in communes farther away from the CBD would have significantly longer commutes times since they live farther away from where most jobs are. Higher levels of entropy causing higher commute times is not very consistent with the literature (Cervero & Kockelman, 1997; Frank & Pivo, 1994) however, in the case of Santiago where congestion is such a big problem, it's possible that areas with more mixed uses are areas with greater congestion. Nonetheless, it would be expected for the density variable to then also be significant.

As for income, communes with higher income households having shorter commute times could be explained by the fact that most jobs are in those richer communes, as well as the fact that in some cases commuting by private vehicle, which is more common in those richer communes, is faster than public transportation.

Table 3. Regression of urban form and income on commute time (min).

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3
Ln Dwelling Density		0.207**	0.103
		(0.102)	(0.0683)
Entropy (0-1)		0.518***	0.353**
		(0.148)	(0.141)
Ln Road Density		-0.187	-0.0789
		(0.141)	(0.1000)
Ln Dist. to CBD		0.252***	0.178***
		(0.0549)	(0.0452)
Ln Transit Density		0.00222	0.00793
		(0.0114)	(0.00934)
Ln Income	-0.355***		-0.259***
	(0.0738)		(0.0756)
Constant	8.773***	2.139***	6.381***
	(1.003)	(0.505)	(1.103)
Observations	45	45	45
R-squared	0.446	0.442	0.635

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Discussion and conclusion

The goal of this thesis was to answer the question "what aspects of the built environment and average household income help explain mode choice as well as commute distance and time in the communes of Santiago, Chile?" Through the use of multivariate regression analysis it became apparent that neighborhood income is one of the most important factors determining commute mode choice as well as commute distance and time. Santiago communes that house richer households tend to commute more by private vehicle while enjoying shorter and faster commutes. Characteristics of the built environment had less of a consistent effect on commuting patterns yet some relationships exist particularly with the distance of the commune to the central business district. People living in neighborhoods farther from the center commute for longer and farther distances than those living closer. Issues related to congestion seem to explain the other results of this study that found that higher transit densities are associated with a higher share of commutes by private vehicle and that more land use mix is associated with longer commute times.

Sensible planning policies could help mitigate some of the effects that economic development and increased motorization could have on emissions in the city. This and previous research on Santiago (Gainza & Livert, 2013; Zegras, 2003) point to the need for policies that reduce the disparities between communes as a key mechanism to minimize the environmental impacts of commuting. Policies like locating more employment in lower-income communes could reduce the need for those living there to travel as far. Since increasing density does not appear to be a mechanism through which travel behavior can be influenced in Santiago, making employment opportunities be more widespread throughout the city could shorten commute times and distances for many people.

However, as long as economic growth continues in Chile, motorization rates will increase leading to greater use of private vehicles for commuting. Making sure that public transportation can offer an attractive alternative despite the convenience of a car is essential. A big obstacle to overcome will be to reduce transit times by public transportation (Herrera & Razmilic, 2016). While the average commute time in the survey overall was 52 minutes, for commutes completed by public transport the average was slightly longer at 59 minutes and by private vehicle was 46 minutes. Implementing the Transantiago was an important first step that has seen ridership go up as well as attitudes towards using public transportation improve (Muñoz et al., 2014). Supporting the well-functioning of this system as well as investing in infrastructure for non-motorized transport can lead to positive results with respect to lowering emissions as witnessed in Mexico with a program started there to support urban mass transit (World Bank, 2017). Furthermore, changing attitudes that relate social status to vehicle ownership will be essential to slowing the rate of motorization (Lankao, 2007). A next step would be to alleviate congestion through improving infrastructure and/or by implementing a congestion pricing scheme (Herrera & Razmilic, 2016; Lopez-Ghio et al., 2018) that could help reduce travel times and therefore diminish incentives for switching to a private vehicle.

Given the differences between cities in Latin America and those in Europe and North America, this research provides an important contribution to the existing research that is heavily weighted towards urban Global North based estimates. In contrast, Santiago exhibits higher levels of urban density that appear to have less of an effect on travel behavior, yet contribute to levels of congestion. Furthermore, extreme neighborhood inequality, coupled with a monocentric city structure, act as magnets attracting most residents, and especially the poor, to richer and more central communes. Concentrating on decentralizing areas of employment to reduce spatial and social inequality and alleviating congestion to improve the appeal of public transportation, could lead to significant changes in travel behavior.

This paper is just a preliminary study on the relationship between urban form and travel behavior in Santiago, thus the results come with some limitations. First, resident self-selection was not controlled for. Although this happens quite often in these types of studies (Ewing & Cervero, 2010) it is still important to highlight the fact that people might choose to live in certain neighborhoods because of their preferences for an automobile or transit oriented lifestyle. People who dislike driving might be more likely to live in the city center, making it seem like being close to the city center increases use of public transport when its actually the preferences of the people that live there that create this relationship.

Second, the use of aggregate data from the travel survey and of the communes as a whole can lead to something called the ecological fallacy where individual relationships between an outcome and predictor variable can be much different and sometimes even the opposite of the aggregately measured relationship (Chapman Hall, 2010; Ewing & Cervero, 2010b). Similar to this issue is the Modifiable Area Unit Problem (MAUP) which arises when data is spatially aggregated. The results of statistical analysis depend on the areal units in which the data is aggregated and can vary significantly depending on the method chosen (Fotheringham & Wong, 1991; Gehlke & Biehl, 1934; Jacobs-Crisioni, Rietveld, & Koomen, 2014). For example, some communes might seem richer than they truly are because of the presence of very rich as well as very poor residents. Grouping them all in one commune raises the average income causing the results of the analysis to be misleading. Nonetheless, this study does not pretend to make any assumptions at the individual level on causal relationships between the built environment and commuting behavior. Future research, however, could attempt to pair neighborhoods in Santiago that have similar average household income yet distinct built environment characteristics. This method would allow the effects of the built environment on commuting times to be more accurately observed (Cervero, 1996). Additionally, looking at individual level characteristics that motivate certain commuting behaviors would be a logical subsequent research approach.

Even so, the main contribution of this study was to show that what we know about urban form and commuting behavior should not be based solely on studies from North America and Europe. Higher levels of urbanization and density, less urban development restrictions, more spatial inequality and higher levels of public transportation use make previous findings difficult to apply to Latin American cities. Future research needs to be done on more cities in the developing world where cities are growing faster and bigger leading to more private vehicle usage which can have dire consequences for air pollution and climate change not only in Latin America but around the world.

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Appendix A: Pearson Correlations (significant correlations highlighted)

	% Private Transportation	Commute Distance	Commute Time	Dwelling Density	Population Density	Entropy	Road Network Density	Distance to CBD	Public Transit Density	Income
% Private Transportation	1									
Commute Distance	-0.2663 0.077	1								
Commute Time	-0.5786* 0	0.5509* 0.0001	1							
Dwelling Density	-0.1445 0.3435	-0.6406* 0	-0.098 0.5218	1						
Population Density	-0.1735 0.2544	-0.6114* 0	-0.042 0.7842	0.9968* 0	1					
Entropy	-0.0485 0.7518	0.0164 0.9147	0.3345* 0.0247	0.1006 0.5107	0.1308 0.3917	1				
Road Network Density	-0.0969 0.5268	-0.6240* 0	-0.1006 0.511	0.9824* 0	0.9854* 0	0.1742 0.2525	1			
Distance to CBD	-0.0292 0.8492	0.8457* 0	0.3680* 0.0129	-0.8664* 0	-0.8466* 0	-0.0219 0.8864	-0.8446* 0	1		
Public Transit Density	0.0166 0.9141	-0.5628* 0.0001	-0.0756 0.6216	0.8696* 0	0.8680* 0	0.0834 0.586	0.8540* 0	-0.7497* 0	1	
Income	0.7605* 0	-0.3587* 0.0155	-0.6677* 0	0.0315 0.8373	-0.0049 0.9745	-0.1752 0.2495	0.0544 0.7226	-0.1943 0.2008	0.0612 0.6897	1