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Abstract

Car dependence is a dimension of transport poverty whose subjective components have been limitedly explored. Research on car dependence highlights the incidence of transport costs, assesses the multidimensional vulnerability of car-dependency and the possibility to access valued opportunities. However, people's perceptions and their perceived ability to access destinations may better reflect the way they move in car dependent settings. In this paper, we aim to examine what are the determinants of perceived accessibility and to which extent perceived accessibility influences mode choices in such areas. Based on a survey carried out in four peripheral and periurban municipalities in the Metropolitan Region of Santiago de Chile, we examine how subjective perceptions of accessibility contribute to explain modal choice in the outskirts. Results show that perceived accessibility has a negative net impact on the utilities for both car and public transport, which means that a low perceived accessibility increases the likelihood of choosing motorized modes. Moreover, residents from peripheral municipalities tend to perceive a higher accessibility than households from periurban areas, who are excluded from the public transport system. These findings show the importance of providing nearby opportunities and convenient alternatives to limit car dependency, especially in periurban areas.

Keywords: discrete choice, mode choice, perceived accessibility, travel behavior, periphery, car dependence

1. Introduction

Car dependence can be defined as a situation in which there is a lack of both alternative transport modes to the car and opportunities near residential places, implying that cars become essential to access services, jobs and opportunities (Mattioli, 2016). In car dependent contexts, most forms of transport poverty can be related in one way or another to the dominance of cars over other transport modes, making car dependence a particularly important dimension of transport poverty (Mattioli and Colleoni, 2016). The possibility to own and use a car therefore becomes fundamental in places "built on the assumption of near-universal car access" (Mattioli et al., 2020). As a result, in car-dependent areas, those who cannot afford a private vehicle or lack the autonomy to use one may be socially excluded. Others may end up being forced to spend an important share of their income in order to maintain a car (Tiznado-Aitken et al., 2022). The dependence on cars can also contribute to accessibility poverty, that is, the difficulty to reach key activities: the car in fact becomes fundamental to access opportunities that are located farther away, implying an expansion of activity spaces and increased travel times and costs (Mattioli, 2021).

Transport poverty studies go beyond travel distances, times and expenses dimensions. These include travel expenses, with a focus on fuel (Curl et al., 2018); their relationship with energy and housing costs (Mattioli et al., 2017; Ortar, 2018; Sterzer, 2017); the possibility to engage in various compulsory and non-compulsory activities (Morris, Blumenberg et al., 2020; Morris, Ettema et al., 2020); and the strategies required to access opportunities while coping with transport costs (Belton Chevallier et al., 2018; Tiznado-Aitken et al., 2022). These issues also affect the possibility to reach valued places and opportunities, since moving may imply high monetary and time costs that people may be willing to avoid (Mattioli, 2021). To define this broad concept, Lucas et al.(2016) proposed a multidimensional definition of transport poverty based on five sub-dimensions: mobility poverty, accessibility poverty, transport affordability, exposure to transport externalities and time poverty.

Adequate accessibility levels are essential to move towards sustainable mobility patterns (Bertolini et al., 2005), especially in the Latin American context (Valenzuela-Levi et al., 2021; Núñez et al., 2022). Accessibility poverty, which reflects the existing difficulties - in terms of time, ease and costs - in reaching key activities, has been broadly studied and led the development of many indicators and methods to measure it (Vecchio et al., 2020). In particular, accessibility poverty is often explained through time poverty (i.e. when individuals need to spend too much time travelling, leading them to social exclusion or social isolation). In the Global South, time poverty is a particularly relevant concept, especially in peripheral areas, which are often characterized by long travel times and a limited access to cars (Hernandez & Titheridge, 2016). While accessibility is not the only dimension of transport poverty affected by inequality, as demonstrates the exposure to transport externalities such as air pollution (Gouveia et al., 2021; 2022) it is especially important considering its contribution to the promotion of social inclusion.

While most transport poverty studies focus on objective features (such as travel times or distances), subjective dimensions could also help to explain the forms of accessibility poverty experienced in car dependent settings. As the concept of perceived accessibility explains, how individuals rate their environment and their subjective ability to reach a destination and access opportunities does not necessarily reflect the results of calculated accessibility evaluations (Lättman et al., 2016; 2018). For example, people's perceptions may question the traditional association between cars and freedom (Sheller & Urry, 2000) while in compact urban settings, the possibility to be car-independent may even generate a feeling of freedom (Lagrell et al., 2018). In Sweden, a sample of 2711 Malmö residents showed that bicycle users may also

perceive to have better transport accessibility than car drivers or public transport users (Lättman et al., 2018). Yet, subjective dimensions such as perceived accessibility have received less attention, even if various theoretical frameworks on perceived accessibility have pointed out that perceived accessibility is the actual determinant of human spatial behavior (Vecchio & Martens, 2021; Pot et al., 2021).

Additionally, research on car dependence has overlooked settings outside the Global North. Until now, most works in fact focused on "developed countries" and their suburban areas (Mattioli et al., 2020) but these issues may be equally important also in other areas of the world. Latin America is a good example in this sense. The region shows high levels of socioeconomic inequality, leading to specific forms of transport poverty that are visible especially in the peripheries of urban areas (Vecchio et al., 2020). Valenzuela-Levi (2018) found in his worldwide study that "more unequal countries, and particularly those in which the rich concentrate income, tend to be more car-dependent" (p. 393). Despite having a smaller car ownership rate compared to Global North areas, motorization rates in the region are growing (Yañez-Pagans et al., 2019), determining a higher importance of cars for everyday trips and activities. Finally, the rapid expansion of Latin American cities has generated significant forms of suburban development, with significant implications for the metropolitan mobility patterns and the everyday choices of their inhabitants (Blanco & Apaolaza, 2018; Cox & Hurtubia, 2016; Guzman et al., 2017; Obregón Biosca et al., 2018; Tiznado-Aitken et al., 2023). Therefore, in the rapidly growing suburban areas of Latin American cities car dependence may be a further dimension of transport poverty.

Drawing on these premises, we aim to examine to what extent perceived accessibility influences modal choices in a car dependent setting. We focus on Santiago de Chile, a Latin American setting in which the issues of transport poverty have been widely examined, but only partially considering their subjective dimensions. In particular, we intend to compare peripheral and periurban settings, which share a functional dependence from zones of the city in which most opportunities (jobs, health, etc.) are concentrated, but have different socioeconomic conditions and different access to public transport (Tiznado-Aitken et al., 2023). To do so, we examine the results of a survey involving 298 households in four peripheral and periurban municipalities of the Metropolitan Region of Santiago.

This study therefore provides several contributions to the existing literature. Given the relatively high socioeconomic inequalities in the Global South, individual perceptions might be better suited to measure inequalities than aggregated objective data. Indeed, current methods based on objective data are not sufficient to identify accessibility poverty in the Global South, in particular in periurban and peripheral areas where transport accessibility indicators are not even available for many municipalities, due to a lack of data in these areas. Therefore, to the best of our knowledge, this work is the first to introduce perceived accessibility as an explanatory variable of the mode choice in the Global South context. These results might be particularly relevant to improve transport planning and policies as perceptions might be complementary to objective measures of accessibility. First, the paper discusses the existing mismatching between subjective and calculated accessibility measures by identifying the determinants of perceived accessibility in Latin American peripheries. Second, it points out how perceived accessibility might be particularly relevant to explain mode choice process in periurban and peripheral areas.

The paper is structured as follows: section 2 gives some highlights on the concept of perceived accessibility, section 3 describes our case study, while section 4 presents the theoretical framework of our modelling approach. Section 5 provides the definition of latent variables and

results, while section 6 concludes by providing key lessons about the role of perceived accessibility and future research.

2. Perceived accessibility and mode choice

Accessibility has gained attention as a suitable evaluative approach for assessing the social implications of transport (Lucas, 2012; Martens, 2016; Vecchio et al., 2020), but most studies have mainly focused on "objective" and often aggregate measurements, based on variables such as the total number of opportunities and average observed travel times. These objective features may differently affect the opportunities available to each person, considering diverse individual features, aspirations and choices (Vecchio & Martens, 2021). As a result, subjective features should be considered when dealing with accessibility, since people living in the same place may take different mobility decisions according to several factors – including perceptions (Van der Vlugt et al., 2019).

The concept of perceived accessibility has recently emerged in the transport literature. Perceptions and subjective metrics are relevant since they relate the way people evaluate the conditions in which they live and move (Pacione, 1982). When considering an objective territorial measure of accessibility, individuals may perceive accessibility of their residential location differently according to their constraints, needs and feelings. Various theoretical frameworks on perceived accessibility have pointed out that perceived accessibility is the actual determinant of human spatial behavior (and thus mode choice) and that calculated "objective" measures are designed as a proxy for this perception (Pot et al., 2021). Perceived accessibility may therefore influence travel behavior and therefore have impacts on sustainability issues.

If perceived accessibility "is about how people rate the conditions in which they live" (Lättman et al., 2018), it might often be confounded with other related concepts, such as perceived convenience, easiness to move, or proximity. Yet, perceived convenience corresponds to a perceived ease of use and perceived usefulness of a service, and therefore includes the idea of utility. Easiness to move is related to what is the easier way to move and proximity describes the nearness in terms of space and time. If these concepts are close, perceived accessibility has the specificity to not only include the idea of proximity but also of being able to reach destinations according to our preferences, which is not necessarily easy.

Comparisons between objective and subjective features showed that the two approaches often identify a low level of agreement and mismatching issues. Different studies have been conducted, focusing on walkability and physical activities (McCormack et al., 2008; Ball et al., 2008; Gebel et al., 2011), access to Metro stations (Shao et al., 2022) existing socio-spatial inequalities related to transport (Curl, 2018; Ryan and Pereira, 2021) or mobility accessibility (Lättman et al., 2018).

This mismatching has been explored in relation with different settings. In Australia, Ryan et al., (2016) explored this mismatching in relation with age groups or transport modes. Results showed that older people experienced the lowest accessibility while middle age are associated to the highest. In Sweden, Lättman et al. (2018) showed that levels of calculated "objective" accessibility do not allow predicting perceived accessibility in a given residential area, but also highlighted that levels of perceived accessibility differ between main transport modes. Perceived accessibility appears to explain also how people decide to move, but until now, few studies integrated this as an explanatory variable in mode choice modelling. In Hong Kong, Tam et al. (2010) integrated perceived service quality in an airport ground access mode choice model. This variable was defined according to satisfaction level on five selected service

attributes related to walking time, distance, reliability, travel costs and travel time. Then, in the Netherlands, Scheepers et al. (2016) introduced perceived accessibility to shops, public natural spaces and sports facilities in their neighborhood by car, bicycle and walk in a mode choice model, exploring more specifically the purpose of the trips. Results showed that when perceived accessibility by car was high, persons were more likely to use the car instead of active transport modes. More recently, in Taiwan, a study included includes perceived accessibility as a predictor for behavioral intention based on MaaS users' service experience (Chen & Chen, 2023). Yet, these studies were focusing on Global North settings and the latter did not distinguish different residential places.

3. Case study and data

3.1. Santiago de Chile: an unequal metropolis

The Metropolitan Region of Santiago (SMR), the capital and main city of Chile, hosts more than 7 million inhabitants. The Greater Santiago is composed of 34 autonomous municipalities, but at least 14 outer municipalities are also strongly connected to the urban center and constitute the functional urban area (Fuentes et al., 2018). Santiago and Chile are representative of urban trends that can be found in other Latin American countries and more in general in the Global South, including intense forms of urban growth, expansion of peripheral and periurban areas, and the emergence of segregated urban structures (Cox and Hurtubia, 2021; 2022). In Chile, almost 90% of the population lives in a city, and 60% of the population lives in the SMR. The periurban areas of Santiago experienced intense demographic growth and land use changes (Banzhaf et al., 2013) in the last few decades, especially outside the urban growth boundaries established in regional plans (Schuster Olbrich et al., 2022), and highways often acted as a push factor for this suburban growth (Borsdorf et al., 2007; Garreton, 2017).

Nonetheless, the case of Santiago has experienced forms of segregation that are stronger – and more intentional – than most other areas. Between 1979 and 1985, an eradication policy implemented by the dictatorship displaced families away from the eastside areas that are today occupied by a concentration of high-income residents and the main economic activities (Suazo-Vecino et al., 2020). As a consequence, the poorest households are often living in low accessibility areas with few job or school opportunities (Tiznado-Aitken et al., 2021), making most work-related trips being directed towards the eastern part of the city, with travel expenses representing a high share of the income for many lower income households. Indeed, the highest transport costs (in terms of both time and monetary expenses) are associated to the highly segregated areas of the territory (location, land prices, accessibility), and concentrated in the areas inhabited by the most deprived groups, which tends to reproduce the existing dynamics of socio-spatial inequalities (Iglesias et al., 2019; Moreno Alba et al., 2021; Tiznado-Aitken et al., 2022).

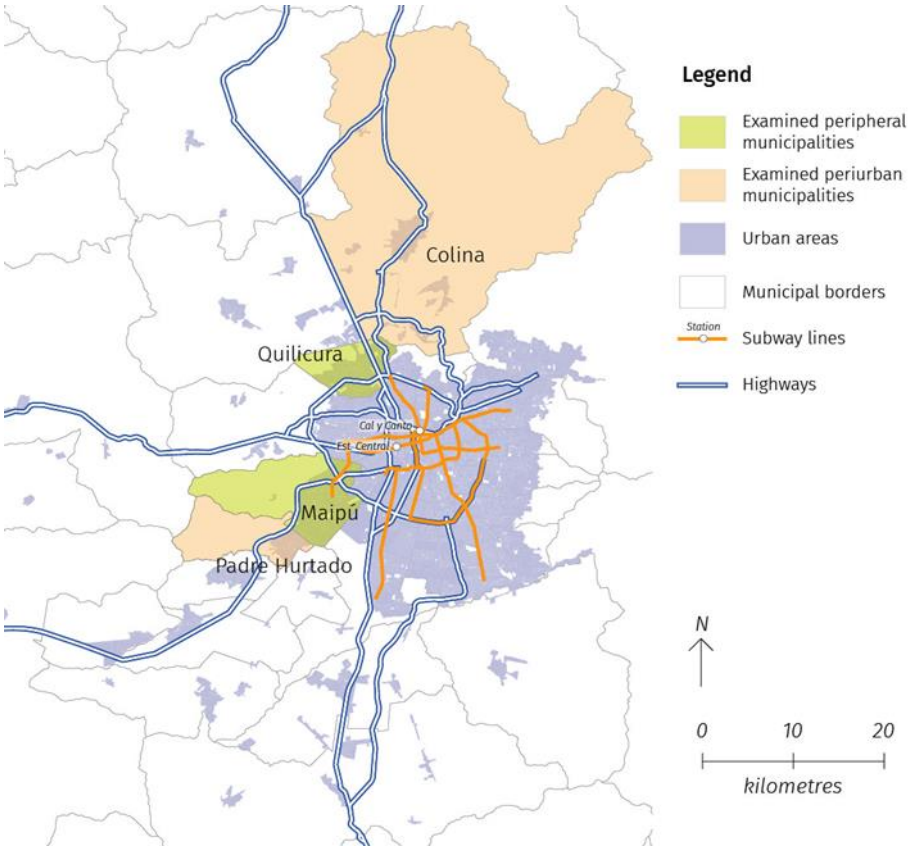

Figure 1 Location of the four examined municipalities in the SMR *(Source: Authors' own elaboration)*

The SMR is also affected by governance issues that condition the effectiveness of its transport system. Santiago lacks a metropolitan authority in charge of urban and/or mobility issues, and therefore, the integrated public transport network is available only for the 32 urban municipalities of the city. In our study, we chose to compare four municipalities (see Table 1 and Figure 1): two peripherals but included in the public transport system perimeter (Quilicura and Maipú) and two contiguous periurban municipalities (Colina and Padre Hurtado) that are located out of the official city borders. In the latter, independent bus lines exist and allow to connect with the integrated system and thus important hubs located in the center of Santiago. Yet, fares are not integrated, the covered distances are huge and so are the travel times; for instance, 32 km separate Colina center from the Costanera Center (approximately the center of mass of the CBD), which represents on average a trip of more than one hour and a half by public transport. Moreover, in peripheral areas, bus stops can be far from residential locations and trips can also be dangerous, for instance if walking at night or close to a highway is necessary to get home (Jirón & Mansilla, 2013). As a result, despite having integrated and frequent public transport services, some peripheral areas are characterized by equal or even higher travel times than periurban areas, which are spatially further from the economic center though (Tiznado-Aitken et al., 2023).

Table 1 Description of the four municipalities of interest

	Quilicura	**Maipú**	**Padre Hurtado**	**Colina**
Type	Peripheral	Peripheral	Periurban	Periurban
Population (2017)	210 410	521 627	63 250	146 207
ICVU (2021)[1]	56.23	53.15	49.38	51.49
ICVU CoMo (2021)	67.56	72.05	58.59	50.79
Area	57.5 km²	135.5 km²	80.8 km²	971.2 km²
Distance to CBD[2]	16.5 km	25.0 km	35.8 km	31.0 km

Because of all these cumulated difficulties, car-dependency issues are very important in Santiago. These mobility constraints concern everyone, as the inhabitants have to manage complex and expensive travel chains if they want to use combinations of active and public transport. In Santiago, car use considerably increased in the last few years, especially during the pandemic, therefore increasing travel times associated with the congestion costs (Muñoz et al., 2022). However, not everyone can afford its purchase and use, and low-income population is often captive of public transport, while many mid-income households live in car-oriented peripheral zones, under a very high financial and time stress due to depending on their cars for their daily mobility (Cáceres Seguel, 2015). At the same time, high-income households prefer to use a car, as observed in Buenos Aires (Blanco and Apaolaza, 2018) and Santiago (SECTRA, 2015). The preference for private vehicles is often justified by the comfort and the cheapness of the vehicles, as cars in Chile have a lower relative and real final price than in the rest of the countries of the region (Figueroa & Rodríguez, 2013). For those who can afford it, results show a high inelasticity compared to the direct cost of its use: despite fuel price increases, there is no observed traffic reduction in the short or medium term (Cortés Salinas et al., 2016).

3.2. Data collection

We used data from a survey developed within the project [*omitted for anonymity reasons*]. The interviews were conducted by phone in the last months of 2021, when some pandemic-related restrictions were still in place, but most in-person activities had resumed. In Santiago, 298 residents from the four examined municipalities were asked to describe their trips related to work, educational, shopping and health purposes. Although this is not a representative survey, the panel of respondents shows an acceptable distribution of several key variables of the metropolitan population, particularly in terms of gender and income[3]. Our dataset highlights the existing differences between periurban and peripheral residents, in terms of age or income (see Table 2).

[1] The ICVU (Indice de Calidad de Vida Urbana, index for urban life quality) measures and compares several life quality index in 99 Chilean cities, covering more than 79% of the population. In particular, the ICVU has a component dedicated to the measurement of "connectivity and mobility" (ICVU CoMo) according to seven variables. The higher is the component; the best are connectivity and mobility and therefore the most accessible is the municipality. See http://icvu.observatoriodeciudades.com/ for more information.

[2] The distance to CBD has been calculated as the distance (by car) between the considered municipality city center and the Costanera Center, often considered as the CBD of Santiago.

[3] In Metropolitan Santiago, 51.3% are women, the average household size 3.1, 62% declare to have a job, and there are 15.5 people 65 or older every 100 people between 15 and 64 (INE, 2017). Regarding income distribution, 30% are up to 2.07 minimum wages, 40% between 2.07 and 4.23 minimum wages and 30% over 4.23 minimum wages (minimum wage reference: 270,000 CLP in 2017) (CASEN, 2020)

Table 2 Descriptive statistics of the sample

Observations: 298 households		*Share (%)*		
		Total *(298)*	Periurban *(101)*	Peripheral *(197)*
Gender	Male	41.3	43.6	40.1
	Female	58.7	56.4	59.9
Age	18 to 30	16.1	15.8	16.2
	30 to 40	20.8	24.8	18.8
	40 to 60	46.6	47.5	46.2
	60 or older	16.5	11.9	18.8
Household size	2 or less	16.9	14.1	18.5
	3	24.1	27.3	22.1
	4	31.0	25.3	35.3
	5 or more	28.0	33.3	24.1
Income (€)	Up to 2 minimum wages	34.5	21.7	40.6
	2 to 4 minimum wages	29.6	25.0	31.8
	More than 4 minimum wages	35.9	53.3	27.6
Number of cars	None	45.4	10.9	23.4
	One	43.0	35.6	51.8
	Two	10.2	34.7	21.8
	Three or more	1.4	18.8	3.0
Employment status	Regular worker	54.6	65.3	57.9
	Student	3.8	3.0	4.6
	Unemployed	19.4	9.9	15.7
	Housekeeper	12.4	10.9	13.7
	Pensioner	9.8	10.9	8.1

Moreover, respondents provided information on their perceptions regarding travel behavior and their environment for a set of 15 psychometrics indicators based on 5-levels Likert scale affirmations (see Table 3). These affirmations are related to different transport poverty dimensions (Lucas et al., 2016) such as mobility issues, affordability or monetary expenses, accessibility barriers and easiness to move, and exposure to externalities, including pleasantness of environment, quality of sidewalks or feeling of safety. Answers associated with these affirmations were coded using a 1 to 5 scale. While this question was not designed to explore perceived accessibility in the first place, our hypothesis is that some of these statements could be used to identify indicators of the latent variable "perceived accessibility".

Table 3 Descriptive statistics of psychometrics indicators (shares in %)

I	Description	(Strongly) disagree	Neutral	(Strongly) agree
I1	Getting around the city is cheap	65.4	15.1	19.5
I2	You choose the means of transport you use most often because it is the cheapest	46.1	13.2	40.7
I3	You use your usual means of transport because it is the only one available	26.4	15.3	58.3
I4	The locations where you need to go are close to your home	19.9	19.9	60.3
I5	It is easy for you to get to the places you need to go	19.5	16.1	64.4
I6	If you were living somewhere else, it would be easier for you to get to where you need to go	22.9	20.1	57.0
I7	The environment in which you move is pleasant	14.8	15.1	70.1
I8	The environment in which you move has good quality streets and sidewalks	31.0	14.8	54.2
I9	The environment in which you move has good quality cycling infrastructure	54.4	15.8	29.9
I10	Some of your journeys involve other family members	62.0	7.1	31.0
I11	When you leave home, you usually take the opportunity to do several activities before returning home	13.4	11.1	75.5
I12	Other people depend on you to get around the city	46.0	9.1	45.0
I13	You feel insecure because of possible accidents you may suffer when moving around	25.5	15.8	58.7
I14	You have been injured while driving	65.9	8.4	25.7
I15	In general, you feel satisfied when you move	20.5	23.6	55.9

Then, respondents provided the destinations of their trips and the transport mode they used (see Table 4), allowing to calculate the associated travel times and distances. These variables were computed using the OpenTripPlanner API[4] for active modes and car options. For public transport, the API was used only to calculate the trips that can be made with the urban public transport system (n=257 trips), since no GTFS files are available for periurban areas in SMR. For travel originating in or directed to these zones, we estimated a travel time connection to Cal y Canto metro station (45 min) for Colina and to Estación Central metro (59 min) for Padre Hurtado. The choice for these connection places has been conditioned by the destination of the few existing bus lines. These estimations come from the travel times declared by the bus companies. We excluded three outlier observations and all the incomplete answers. Each respondent may be associated with one or two observations depending on their answers for work and health issues (shopping and educational trips were excluded, as the exact destination address was not provided). In the end, the useful database is composed of 399 complete trip observations relating mobility habits, psychometric indicators (perceptions) and socioeconomic attributes. This case study is further analyzed in Blandin (2023) and Hurtubia et al. (forthcoming).

Table 4 Modal shares by residential location

	Quilicura (N=119)	Maipú (N=142)	Padre Hurtado (N=62)	Colina (N=76)
Car	48.8%	45.8%	72.6%	78.9%
Public transport	37.0%	41.5%	24.2%	15.8%
Active modes	14.2%	12.7%	3.2%	5.3%

[4] See https://www.opentripplanner.org/ for more information.

4. Methods: defining the integrated choice and latent variable model

To explain mode choice, the majority of the existing models relies on the use of modal attributes and socioeconomic characteristics (Ben-Akiva & Lerman, 1985), but unobserved factors may have relevant effects on travel behavior, such as perceptions of the environment, accessibility, feasibility. In this sense, the framework of modeling choice behavior was extended with the emergence of the Integrated Choice and Latent Variable (ICLV) model (Ben-Akiva et al., 1999; Walker and Ben-Akiva, 2002). In ICLV models, psychometric indicators are used to measure attitudes and/or perceptions, taking the form of affirmations to which respondents are asked about their level of agreement. These indicators are useful to relate the individual's characteristics with unobserved or latent variables, allowing to build structural relations that can be later used to include the latent variable in a choice model.

In the literature, latent variables included in ICLV models focusing on mode choice are related to a wide range of concepts, reflecting the multiple dimensions of the decision process. For instance, these variables may be related to lifestyle and or/trip constraints, as individuals may have to face different types of constraints when travelling, whether in terms of duration, location and timing or the need to travel with children (Redmond, 2000). Other variables may be linked with travel liking: individuals may be characterized by positive feelings and perceptions when travelling, which decreases their value of time. For example, some people enjoy their travel times in order to work or do other activities (Ory & Mokhtarian, 2005). Safety perception when travelling may explain mode choices (Raveau et al., 2010). For example, the fear of accidents when moving and/or and driving-related injuries may show driving avoidance when not necessary and therefore create a preference for other transport modes. Other studies have also included other variables such as comfort, convenience and flexibility (Vredin Johansson et al., 2006), social comparison (Abou-Zeid & Ben-Akiva, 2011), environmental concerns (Atasoy et al., 2013), values and attitudes (Paulssen et al., 2014) or habitual behaviors (Idris et al., 2015).

As defined earlier, perceived accessibility reflects individuals' perceptions and feelings related to the ability to reach a destination considering the whole range of personal opportunities and constraints associated to their specific mobility behavior. Therefore, it may be useful to explain individual preferences for choosing a transportation mode.

The general structure of the ICLV model is described in Figure 2. Rectangles represent observable variables while ovals represent unobservable and latent variables. Continuous arrows show the structural relations between observable and unobservable variables with the choice model and dotted ones represent the relations between observable variables and the latent variable. In this paper, we use the ICLV model to explain mode choice considering a set of three alternatives considering car, public transport or active modes. In our case, the dependent variable is the transport mode chosen by a respondent. Other variables are related to the socio-economic characteristics of the households, trip attributes and location characteristics. The psychometric indicators allow to define the latent variable of perceived accessibility (which is unobservable, but defined from indicators and individual characteristics).

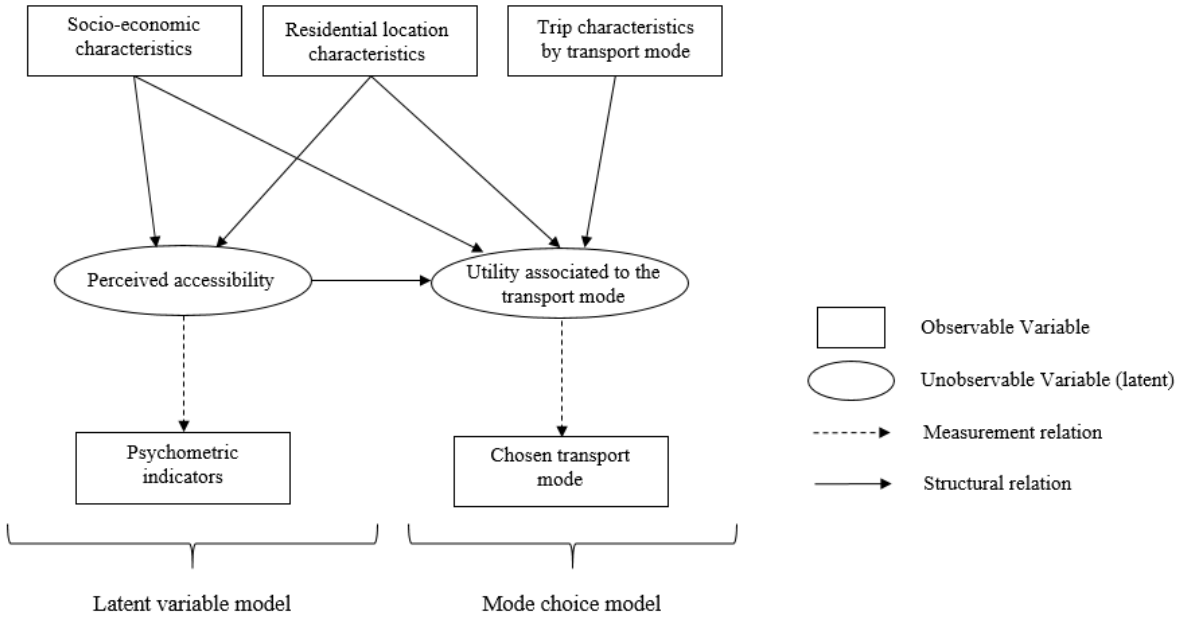

Figure 2 ICLV model

An ICLV model consists in the combination of two components: a structural equation modelling (SEM) and a discrete choice modelling (DCM). For an individual *n*:

The SEM measurement equations that allow describing the relation between the psychometrics indicator and the latent unobservable variable are:

$$I_n = f(X_n^*; \zeta) + v_n \quad (1)$$

where the indicator *I* is a function of the latent variable *X**, a set of parameters ζ and an error term (*v).*

The latent variable can also be related to observable explanatory variables X (the characteristics of the household, the residential location). This relation is described by the SEM structural equation:

$$X_n^* = g(X_n; \gamma) + w_n \quad (2)$$

where γ is a set of parameters and *w* is an error term.

For each transport mode (described as an alternative *i*, for an individual *n*), we write a utility function:

$$U_{in} = V(X_n, X_i, X_n^*; \beta) + \varepsilon_{in} \quad (3)$$

where *V* is the indirect utility function, β a set of parameters and ε an error term.

In a utility maximization framework, the probability for individual *n* to choose alternative *i* in a set of alternative denoted A is:

$$P(i|X_n, X_i, X_n^*; \zeta, \sigma_\varepsilon) = \text{Prob}\left[U_{in} \geq U_{jn}, \forall j \in A\right] \quad (4)$$

where σ_ε is a vector of parameters of the error term related to ε.

As the latent variable X* is not observable, it requires to integrate over the distribution of the latent variable. Using the associated density functions, we obtain:

$$P(i, I_n|X_n, X_i;\ \beta, \zeta, \lambda, \sigma_\varepsilon, \sigma_v, \sigma_w) = \int_{X*} P(i|X_n, X_i, X^*; \beta, \sigma_\varepsilon)\, f(I_n|X^*; \zeta, \sigma_v) f(X^*|X_n; \gamma, \sigma_w) dX^* \quad (5)$$

Estimating the parameters implies maximizing the likelihood function of observable variables and indicators. The likelihood function (L) is:

$$L = \sum_n \sum_{i\ in\ A} \theta_{in} P(i, I_n|X_n, X_i;\ \beta, \zeta, \lambda, \sigma_\varepsilon, \sigma_v, \sigma_w) \quad (6)$$

In the literature, many researchers used this approach and applied it to the transport field, focusing in different issues such as mode choice (Ben-Akiva and Boccara, 1995; Espino et al., 2006; Hurtubia et al., 2010), car choice (Bolduc et al., 2008), residential location choice (Walker & Li, 2007) or cycling infrastructures (Rossetti et al., 2018).

5. Results

In this section, we first present the steps followed to identify the latent variable, and then describe our results when applying the model.

5.1. Identification of the latent variable

We conducted a factor analysis which generated 5 relevant factors with an eigenvalue greater than 1, that together explain 54.19% of the total variance (see Appendix A for more details). We used a Varimax rotation to ease the identification of each variable with a single factor. We did not conduct a previous cluster analysis of the data, as the size of the dataset was not large enough for this purpose. The set of results detailed in Table 5 are limited to indicators associated with an absolute value greater than 0.2 and a 95% significant level.

Table 5 Loading factors associated to the psychometric indicators

I	Description	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
I1	Getting around the city is cheap					0.366
I2	You choose the means of transport you use most often because it is the cheapest			0.277		0.519
I3	You use your usual means of transport because it is the only one available			0.363	0.247	
I4	The locations where you need to go are close to your home	0.775				
I5	It is easy for you to get to the places you need to go	0.558			0.367	
I6	If you were living somewhere else, it would be easier for you to get to where you need to go	-0.285		0.246		
I7	The environment in which you move is pleasant		0.351		0.275	
I8	The environment in which you move has good quality streets and sidewalks		0.564			
I9	The environment in which you move has good quality cycling infrastructure		0.764			
I10	Some of your journeys involve other family members			0.346		
I11	When you leave home, you usually take the opportunity to do several activities before returning home				0.453	
I12	Other people depend on you to get around the city			0.228		-0.375
I13	You feel insecure because of possible accidents you may suffer when moving around		-0.202	0.440		
I14	You have been injured while driving			0.534	-0.201	0.212
I15	In general, you feel satisfied when you move	0.291			0.429	

By analyzing the corresponding indicators and their signs, it is possible to infer the latent variable associated to each factor. Focusing on factor 1, we observe that a high level of agreement with affirmation 4, 5 or 15 demonstrates a feeling of having easy access to opportunities, few difficulties reaching the needed destinations and a positive perception of moving. On the contrary, factor 1 is associated to a disagreement with affirmation 6, meaning that the current residential place appears to be satisfying considering mobility purposes. This shows that factor 1 can be identified as the individual "perceived accessibility" latent variable, defined as "how easy it is to live a satisfactory life with the help of the transport system" (Lättman et al., 2016).

Before going any further, we underline that perceived accessibility is a complex issue, which is often mixed up with other similar concepts such as perceived convenience, easiness to move or proximity. Consequently, areas that might objectively be described as having low accessibility can still be attractive for residents who perceive it more positively. Despite not being very accessible in terms of travel times and distances, people seem to value the environment in which they live; other elements may therefore explain their residential choices. For instance, some areas may be objectively described as having low accessibility considering all available opportunities, but in reality, households might need a limited amount of close or reachable services to have a high-perceived accessibility.

In our specific case, perceived accessibility appears to be particularly related to the close environment. In this sense, exploring in detail the different factors leading to the construction of the perceived latent variable might offer great insights on the differences observed with the Global North context and highlight what is missing in the current accessibility evaluations.

Moreover, the inclusion of a satisfaction while traveling item in the definition of our perceived accessibility variable differs from the definition provided by Lättman et al. (2016), which is related to satisfaction using a specific mode. It is reasonable to assume that individuals with higher perceived accessibility are likely to be more satisfied with their travel, as this may help bridge the gap between expectations and what is experienced (Stradling, Anable, & Carreno, 2007). This relation has been explored in the literature, proving to be complex (Lattman et al., 2019; De Vos et al., 2023). For example, lower actual commuting times are associated with higher travel satisfaction, while potential accessibility is not (Pritchard et al., 2021), suggesting again that subjective accessibility indicators are better predictors of behavior than objective ones and that including indicators for travel satisfaction in the measurement of perceived accessibility is convenient. Recent efforts have been proposed in this direction, finding a significant discrepancy between standard gravity and satisfaction-based access measures (Chaloux et al., 2019).

A similar analysis performed with factors 2 to 5 allowed to identify other latent variables such as amenities (factor 2), safety (factor 3), and utilitarian travel (factor 5) while factor 4 is not easily identifiable. Yet, we decided to restrict our analysis to the effect of one latent variable in order to focus on the analysis of the potential for perceived accessibility to explain mode choice.

5.2. Model specification

We specified a logit model including latent variables as defined in section 2. Here, the choice is the transport mode that is used for a trip, considering a set of three alternatives: car, public transport or active modes (bicycle, walk). For each alternative, we defined a utility function:

$$V_{car} = ASC_{car} + \beta_{tt_{car}} TT_{car} + \beta_{cost_{car}} cost_{car} + \lambda_{car}\, access + \beta_{income_{car}} * income + \beta_{peripheral_{car}} * MQ + \sum_{k} \beta_{k_{car}} \delta_k \quad (7.1)$$

$$V_{pt} = ASC_{pt} + \beta_{tt_{pt}} TT_{pt} + \beta_{cost_{pt}} cost_{pt} + \lambda_{pt}\, access + \sum_{k} \beta_{k_{pt}} \delta_k \quad (7.2)$$

$$V_{active} = ASC_{active} + \beta_{tt_{active}} TT_{active} \quad (7.3)$$

Where TT variables represent travel times in minutes, *income* is the monthly income described as the number of minimal wages earned monthly, and MQ indicates if the household lives in peripheral municipalities (Maipú or Quilicura). δ_k is a vector of socio-economic characteristics, which includes dummy variables for number of cars, gender, presence of children, trip purpose (work or health), and educational level. The latent variable, denoted *access*, represents the perceived accessibility.

The SEM measurement equations are estimated using ordered logit with four thresholds as our psychometrics indicators follow a 5-levels Likert scale. The thresholds are denoted τ_{ij} with *i* within a range from 1 to 4 and *j* = 4, 5, 6 and 15, corresponding to the 4 most relevant psychometrics indicators identified in section 5.1 (Equation (8)).

$$I_j = \begin{cases} 1 \ if \ I_j^* < \tau_{1j} \\ 2 \ if \ \tau_{1j} < I_j^* < \tau_{2j} \\ 3 \ if \ \tau_{2j} < I_j^* < \tau_{3j} \\ 4 \ if \ \tau_{3j} < I_j^* < \tau_{4j} \\ 5 \ if \ I_j^* > \tau_{4j} \end{cases} \qquad \forall\, j = 4, 5, 6, 15 \quad (8)$$

Estimation results for the measurement equation are shown in Appendix B.

The latent variable is composed by two variables, corresponding to education and declared travel time. For an individual *n*, the structural relation between the latent variable perceived accessibility, denoted *access*, and the socio-economic characteristics is given by:

$$access_n = \gamma_{time}(1 + \gamma_{MQ}\, MQ_n) time_n + \gamma_{educ}\, EDUC_n + w\#(9)$$

Where *time* corresponds to the average declared travel time, without distinction on trip purposes or transport mode. It is an approximation of the perceived travel time and is not necessarily realistic, but sufficient to explain perceived accessibility. MQ_n is a dummy variable equals to 1 if the respondent lives in Maipú or Quilicura (the peripheral municipalities) and $EDUC_n$ is a dummy variable that indicates if individual *n* has a university degree.

5.3. Influence of perceived accessibility in the model

Results are obtained by using the Apollo package in R (Hess & Palma, 2019). Table 7 provides the estimation results of the ICLV model and a comparison with a logit (MNL) model.

The ICLV model allows for the identification of structural relationships between observable and latent variables, which would not be possible using the reduced form choice model. In comparison with the logit model, the latent variable approach allows to remove some

endogeneity bias and identify additional relevant parameters to explain mode choice (Vij & Walker, 2016).

All the parameters have the expected signs. We observe that a higher travel time has a negative impact on the utility function of all modes ($\beta_{tt} < 0$). Moreover, earning a high income, having more than a car ($\beta_{nvh_{car}}$) and having a university degree ($\beta_{educ_{car}}$) has a positive effect on the utility for car, while being a woman or living in peripheral municipalities has a negative effect. In particular, the utility of car is lower in peripheral municipalities, which is consistent with the better overall calculated accessibility observed in this area (as indicated by the ICVU CoMo indicator, see Table 1). This distinction between peripheral and periurban areas was also tested for other modes but was insignificant and therefore removed from the model. Concerning public transport utility, having children has a negative effect while travelling for work purposes ($\beta_{work_{pt}}$) has a positive effect on utility. In the case of work, this can be explained considering the segregated urban structure of Santiago, since most formal job opportunities are concentrated in the affluent eastern area of the city and several subway lines allow to access it. Similarly, a network of urban highways connects the eastern zone with the periurban areas here examined. Different is the case for health, since facilities that provide primary attention are usually found locally, while specialist doctors are found mainly in structures located in the central and eastern part of Santiago.

We tested the influence of the monetary travel costs on the utility of both motorized modes, which had no significant explanatory power. This could be interpreted as people in this context assuming travel costs as sunken, or unavoidable. In our case, this observation is particularly relevant and can be interpreted as a consequence of the lack of options to travel from periurban and peripheral areas, which strongly affects and conditions the choice of a transport mode. Moreover, the purpose of the trip had not significant explanatory power in the car utility function and was excluded from the analysis. When considering the utility function for public transport, the calculated "objective" public transport accessibility of the municipality and the residential location were also insignificant.

Table 7 Estimation results of the ICLV and MNL models

	Affected utility			**ICLV model**		**MNL model**	
	V_{car}	V_{pt}	V_{active}	Value	t-test	Value	t-test
ASC_{car}	x			0.005	0.08	0.153	0.29
ASC_{pt}		x		-0.359	-0.46	0.273	0.44
ASC_{bike}			x	0	-	-	-
$\beta_{tt_{car}}$	x			-0.053*	-1.70	-0.055*	-1.82
$\beta_{tt_{pt}}$		x		-0.017*	-1.70	-0.015	-1.57
$\beta_{tt_{bike}}$			x	-0.054***	-3.95	-0.056***	-4.33
$\beta_{cost_{car}}$	x			-6.97e-5	-0.60	-5.03e-5	1.1e-4
$\beta_{cost_{pt}}$		x		-1.57e-4	-0.26	-2.86e-5	5.0e-4
$\beta_{income_{car}}$	x			0.214***	3.29	0.203***	3.21
$\beta_{peripheral_{car}}$	x			-0.711*	-1.74	-0.523	-1.24
$\beta_{nvh_{car}}$	x			1.386***	4.59	1.362***	4.62
$\beta_{educ_{car}}$	x			0.720***	2.54	0.714***	2.70
$\beta_{female_{car}}$	x			-0.590***	-2.26	-0.560***	-2.21
$\beta_{child_{pt}}$		x		-0.607***	-2.25	-0.506***	-2.00
$\beta_{work_{pt}}$		x		0.833***	3.09	0.814***	3.14

λ_{car}	x		-1.220***	-2.79	-	-
λ_{pt}		x	-1.560***	-3.45	-	-
γ_{time}	x	x	-0.021***	-4.30	-	-
γ_{time_MQ}	x	x	-0.321***	-2.04		
γ_{educ}	x	x	-0.540***	-2.79	-	-
LL(final)[5]			-266.23		-278.15	

*** p < 0.01, ** p < 0.05, * p < 0.10

The latent variable has a negative impact on the utilities for both car and public transport, which means that a lower perceived accessibility increases the likelihood of choosing these modes, with a slightly more important effect on public transport ($|\lambda_{pt}| > |\lambda_{car}|$). Therefore, a low perceived accessibility increases the probability of choosing to travel by car and even more by public transport. This result is particularly important in terms of transport planning and underlines not only the necessity to provide new mobility options in these territories, but to also explore mechanisms to increase perceived accessibility.

Considering the specification of the latent variable, having a university degree has a negative impact on perceived accessibility, which was expected, as a high-level education is generally associated with higher income and a greater value of time. Then, we observe that subjective (or declared) travel times (γ_{time}) have a negative impact on perceived accessibility (i.e. the longer the trip is perceived, the lower is the perceived accessibility), and therefore, declared travel times have an indirect net positive impact on utilities (opposed to the effect of objective travel times).

Other socio-economic characteristics such as gender, family size, number of cars, or the objective travel times were not significant to explain the latent variable. In particular, the insignificance of objective travel times in explaining perceived accessibility reinforces the idea that there is no clear correlation between perceived and "objective" accessibility, as existing literature shows (Ryan et al., 2016; Lättman et al., 2018).

Finally, households living in peripheral municipalities (Maipú and Quilicura) tend to perceive a higher accessibility, which is consistent with the existing transport supply in these areas. In particular, when comparing the average perceived accessibility in the four municipalities – computed by considering the average value for the responses in the sample – we observe that Padre Hurtado is perceived as the least accessible (*access* = -1.31), while Quilicura is seen as the most accessible (-0.60), followed by Maipú (-0.82) and Colina (-0.91). Yet, objective indicators, such as the mobility component of the ICVU indicator (Table 1), classify Maipú as the most and Colina as the less accessible municipalities, indicating again the existing mismatching between objective and subjective measures of accessibility.

6. Discussion and conclusion

In this paper, we investigated the influence of perceived accessibility on the modal choices realized in an unequal, car-dependent setting such as the Santiago Metropolitan Region. In particular, we identified a relevant latent variable to explain the observed mode choice in peripheral and periurban areas.

First, based on the fact that perceptions appear to better explain individuals' behaviors than objective features, it is particularly relevant to integrate subjective indicators when studying

[5] Final likelihood estimated for each model.

mode choice (J. Ryan & Pereira, 2021). In this sense, our results showed that the introduction of perceived accessibility as an explanatory variable in our mode choice model provided a better understanding of the mode choice in peripheral and periurban areas. In particular, our analysis revealed that perceived accessibility in a Latin American context is determined by different subjective features such as the perceived cost of travelling, perceived quality of the environment and/or availability of different transport modes and especially active modes, in line with other studies led in suburban settings (Chowdhury et al., 2016). Many of these features - related to modal options, travel costs and mobility experiences - also appear in studies conducted in the Global North (see for example Friman et al., 2020; Lättman et al., 2019; Pot et al., 2023). It is interesting to observe these commonalities related to perceived accessibility, since these are found in settings that are very different from our case study in terms of size of the urban areas, existing forms of urban inequality and segregation, and limited availability of transport alternatives, all elements that theoretically may differently influence the perception of accessibility. Therefore, integrating these new dimensions in future evaluations of accessibility in Latin America may be particularly useful to identify more precisely accessibility poverty.

Second, these results are particularly useful for policymakers to tackle car dependency issues by designing equitable public policies and transport planning at the local scale depending on individuals' characteristics and perceptions of their environment. While car dependence is of concern from environmental, externalities and climate change standpoints, the consequences are strengthened for those who are forced to use a car, having to bear costs that may lead to debt or a lower quality of life as they spend less on other dimensions of life. The interplay of environmental and social concerns requires adopting an intersectional approach, focusing on providing affordable and convenient transportation alternatives as well as opportunities and services in their neighborhoods, especially for those at risk of transport poverty. In this context, our results showed that a low perceived accessibility increases the likelihood of choosing to travel by car and even more by public transport in both periurban and peripheral areas. Therefore, increasing residents' (perceived) accessibility is at stake to limit car dependence in these areas. Based on these results, providing near opportunities, improving the moving environment and/or developing active mobility infrastructures may have a positive influence on perceived accessibility and may encourage choosing non-motorized modes. This may be especially important in the post-pandemic era, which has shown car dependency intensification as the pandemic spread (Kim et al., 2023) and long-lasting effects remain to be studied.

Third, in a Global South context marked by strong socioeconomic inequalities and poor transport planning, the study of perceived accessibility is particularly relevant. In particular, perceived accessibility may improve the current measures of accessibility in peripheral and periurban areas, where calculated accessibility is globally low. In Santiago de Chile, periurban areas experienced high levels of urban growth in the last decades, with both high- and middle-income urban inhabitants relocating there looking for features that the city could not offer (Cáceres Seguel, 2015; Cox and Hurtubia, 2021). The increasing motorization rates and the relatively recent growth of periurban areas configure car dependency as a newer phenomenon in comparison to Global North countries, as demonstrated also by the scarcity of data and analysis involving settings outside Europe or North America (Saeidizand et al., 2022). Instead, the inhabitants of peripheral areas often did not decide to live in these places and many of them were relocated to the periphery a long time ago, after the eradication of informal settlements located in the eastern affluent areas of the city. Such relocations had important consequences also for their everyday mobility, increasing greatly travel times (Suazo-Vecino et al., 2019). Our analysis showed that perceived accessibility reveals that the attractiveness of periurban and peripheral municipalities differs from what could be expected with objective measures. This creates a mismatch between expectations and reality that influences the gap between objective

and perceived accessibility. In particular, municipalities that are objectively described as the most accessible, such as Maipú, are perceived as less accessible by residents, who might consider that reaching their destinations considering the current available transport modes set is too complicated, in comparison with Quilicura residents. Moreover, residential self-selection could also be an argument to explain this mismatching, as residents living in the more objective/less perceived accessibility areas might be less interested in the destinations that are included in the objective measures, while those living in more rural areas perhaps are more interested in nearby activities that are nearby in those areas and adapt their travel in line with available services (Pot et al., 2023).

Fourth, satisfaction has been traditionally treated as an outcome of travel experience, which highly varies depending on travel characteristics, choices, and attitudes (De Vos & Witlox, 2017). However, it has been shown that experienced satisfaction can influence travel behavior or even residential location, for example, when users of a transport mode are more likely to locate in areas with higher accessibility for that particular mode (De Vos, 2019). Our results confirm previous results linking travel satisfaction with perceived accessibility (through $\tau_{i,15}$ in Appendix B) providing new evidence on the influence of satisfaction on travel behavior.

Fifth, the observations made for mobility costs, which have a neglectable influence on mode choice for every single mode, are interesting and show that mobility choices are based on different concerns in such periurban areas. Undeniably, in these areas people develop residential and mobility choices having other concerns in mind in comparison to other contexts; moreover, specific differences in terms of low carbon behaviors emerge when comparing urban and suburban residents (Neo et al., 2017; Du et al., 2020). In the case of Santiago de Chile, it has been observed that the people who relocate to periurban areas look for bigger houses and neighborhoods safer than those of the central city, and in doing so, they are willing to internalize the increased costs of mobility and access to opportunities (Cáceres Seguel, 2015). This may explain the high car dependency in periurban areas, which may be the only available option for traveling large distances given the inadequate level of service offered by public transport. On the contrary, it could be imagined that people who remain in peripheral areas and have access to the integrated public transport network may expect to have higher levels of accessibility than those actually available to them, also in comparison to other, more central municipalities of the same city. These attitudes have strong implications in terms of urban planning, underlining the necessity to work not only to make existing modal choices more sustainable, but rather adopting a broader definition of accessibility that may include the attitudes, perceptions and feelings of residents regarding mobility environment (Zhang et al., 2021).

Yet, this work has some limitations that could lead to future research avenues.

The use of a more extensive dataset, including also other peripheral and periurban municipalities should be explored, as it would allow conducting a cluster analysis before modelling and therefore understanding better the existing differences between peripheral and periurban areas. Moreover, the size of our dataset is limited to 298 respondents. The exclusion of some trip purposes such as shopping is also a limit of this work as it would be of interest to study local mobility habits.

Then, the use of complementary psychometrics indicators may also improve the definition and the results associated to the latent variable and other latent constructs that could have emerged if better defined. However, we are aware that this would have increased the survey time, which makes data collection more difficult and therefore demanded decisions about which purposes to prioritize.

Moreover, this paper is based on an analysis of cross-sectional data. Therefore, this paper gives some clues to highlight existing correlations without allowing us to identify causality. Future research should particularly focus on understanding the existing causal relations between residential choice, mode choice and accessibility.

Finally, few information is available to assess objective accessibility in periurban municipalities and particularly in Colina, which is a limit of the analysis. A complementary work on objective accessibility in these specific areas that are poorly documented may be enlightening in order to better understand the differences between calculated and perceived accessibility.

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Appendix A

Table A1 – Synthesis of the identified factors, corresponding eigenvalues and explained variance.

Factor	Eigenvalue	Explained variance	Cumulative explained variance
1	2.65	17.65	17.65
2	1.79	11.91	29.56
3	1.33	8.90	38.46
4	1.27	8.49	46.95
5	1.08	7.23	54.20

Appendix B

Table B1 – Estimation results for the measurement equation (8).

	Estimate	t-test
$\tau_{1,4}$	-5.360	-5.90
$\tau_{2,4}$	-3.711	-5.13
$\tau_{3,4}$	-2.344	-3.95
$\tau_{4,4}$	-0.387	-0.81
$\tau_{1,5}$	-5.754	-5.48
$\tau_{2,5}$	-4.270	-4.84
$\tau_{3,5}$	-2.777	-4.05
$\tau_{4,5}$	-0.196	-0.38
$\tau_{1,6}$	-1.658	-5.03
$\tau_{2,6}$	-0.830	-2.85
$\tau_{3,6}$	0.242	0.81
$\tau_{4,6}$	1.209	3.60
$\tau_{1,15}$	-3.624	-6.22
$\tau_{2,15}$	-2.525	-5.18
$\tau_{3,15}$	-1.020	-2.79
$\tau_{4,15}$	0.532	1.67

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