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POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

Transport Through The Gender Lens: Insights Into Travel Behaviour, Travel Attitudes, And Transport Poverty

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Thèse présentée en vue de l'obtention du diplôme de *Philosophiæ Doctor*

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Transport Through The Gender Lens: Insights Into Travel Behaviour, Travel Attitudes, And Transport Poverty

présentée par **Maria Laura GUERRERO BALAREZO**

en vue de l'obtention du diplôme de *Philosophiæ Doctor*

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Alireza ERMAGUN, membre externe

DEDICATION

To all the women and girls who in some moments have felt the difficulty of moving through the city.

To my Ecuadorian women friends, whose stories of struggle with movement sparked the curiosity to write this study

To my dad, who always encouraged me to pursue my studies, and who would have loved the chance to read this thesis

A todas las mujeres y niñas que en algún momento han sentido la dificultad de moverse por la ciudad

A mis amigas ecuatorianas, cuyas historias de inmovilidad generaron la curiosidad que inspiró este estudio

A mi papi, que siempre me impulsó a estudiar, y quien le habría encantado tener la oportunidad de leer esta tesis.

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The experience of being a migrant implies to live with a divided spirit. A part of me lives in Montreal, which has been a wonderful adventure of discovery. I want to acknowledge the people and dear friends, too many to name, who have touched my life at different points since I got here, and have made this journey warmer and more joyous. Another part of me stays in Ecuador, and so I want to remember and acknowledge my friends there, who I always miss, and who still keep me anchored to that part of my identity, no matter where we are in the world.

RÉSUMÉ

Cette thèse propose des approches analytiques centrées sur le genre, répondant au besoin persistant de méthodes capables de révéler comment les systèmes de mobilité façonnent différemment les expériences des femmes et des hommes. En mobilisant principalement des jeux de données publics ainsi qu'un ensemble diversifié de techniques statistiques et spatiales, la recherche examine comment les services de transport, les formes d'occupation du sol et les caractéristiques socioéconomiques interagissent pour produire des résultats de mobilité genrés. À travers quatre articles, cette thèse démontre que le genre est inscrit dans l'ensemble du système de transport : dans les comportements de déplacement, dans l'organisation spatiale des flux de mobilité, dans l'accès aux opportunités, ainsi que dans les attitudes et perceptions qui influencent les choix modaux.

Le premièr article étudie les différences de genre en matière de pauvreté en transport dans les régions métropolitaines canadiennes. À partir de données de recensement (2016) et de mesures d'accessibilité spatiale (2022) disponibles publiquement, elle applique des indicateurs pondérés par la population pour comparer les niveaux de pauvreté en transport, de marginalisation et d'inaccessibilité entre les femmes et les hommes. Les résultats montrent que les femmes connaissent des niveaux significativement plus élevés de pauvreté en transport et de marginalisation, tout en faisant face à un niveau d'inaccessibilité plus faible que les hommes. Les Indicateurs Locaux d'Association Spatiale (LISA) révèlent des nuances spatiales, identifiant des zones où de fortes concentrations de femmes coïncident avec des désavantages accrus en matière de transport. Ces résultats démontrent que la dimension de genre dans la pauvreté en transport est à la fois mesurable et spatialement structurée, offrant des implications claires pour des interventions ciblées.

Le deuxième article utilise l'Enquête Origine-Destination de Montréal (2018) pour examiner les différences genrées dans les distances parcourues et les profils de destinations. Grâce à une régression linéaire avec bootstrap, les résultats indiquent que les femmes parcourent de plus courtes distances que les hommes, et que la présence d'enfants dans le ménage affecte de manière plus importante les distances parcourues par les femmes. L'écart entre les genres se réduit dans les ménages monoparentaux et à revenu moyen, suggérant que la structure du ménage et le contexte économique modulent la mobilité genrée. Les analyses spatiales utilisant LISA révèlent que les

femmes se rendent plus fréquemment en banlieue pour le travail, les soins et les loisirs, tandis que les destinations des hommes sont davantage concentrées dans les secteurs centraux.

Le troisième article développe une classification tenant compte de la dimension spatiale des flux de mobilité selon le genre à l'aide du Hierarchical Link Clustering (HLC). En classant les flux origine-destination de Montréal (2018) en types de mouvements et en modélisant leurs facteurs explicatifs, l'analyse montre que les flux des femmes sont plus susceptibles d'être locaux ou d'être spatialement allongés et multidirectionnels, reflétant une combinaison d'activités de proximité et de déplacements plus longs. Cette étude révèle également que les types de mouvements se manifestent différemment dans la ville pour les femmes et les hommes, en particulier dans les zones suburbaines on-island (au nord) où les flux allongés et multidirectionnels des femmes sont concentrés. Les résultats de régression indiquent que les types de mouvements des femmes sont davantage liés à des facteurs socioéconomiques, tandis que ceux des hommes sont plus fortement associés à l'usage du sol et aux services de transport.

Le quatrième article explore les différences de genre dans les attitudes envers les modes de transport et leur relation avec la dissonance de déplacement, définie comme un décalage entre le mode préféré et le mode effectivement utilisé. À partir de l'Enquête de segmentation de Montréal (2023), une enquête menée auprès des voyageurs de la région, cette étude applique une analyse factorielle et une modélisation logit multinomiale pour examiner comment les perceptions et les caractéristiques socioéconomiques influencent la dissonance de déplacement. Les résultats montrent que les femmes accordent une importance plus grande aux attributs affectifs et liés à l'efficacité lorsqu'elles évaluent les modes de transport, et qu'elles entretiennent des opinions plus nuancées à l'égard de certains modes. Les hommes, en revanche, ont tendance à évaluer la plupart des modes positivement, à l'exception de l'autobus. L'analyse révèle également que la dissonance de déplacement des femmes est davantage expliquée par des facteurs socioéconomiques, tandis que celle des hommes est plus influencée par les attitudes et perceptions.

Certaines limites sont discutées : des jeux de données manquant de granularité spatiale et de détails catégoriels nécessaires pour saisir pleinement les dynamiques de mobilité genrée, ainsi que l'absence de données suffisantes concernant les personnes non binaires. Ces limites ouvrent des pistes claires pour de futures recherches, incluant des analyses spatiales plus fines de la mobilité liée aux soins, une exploration approfondie du lien entre les destinations de travail et la négociation

des tâches domestiques, ainsi qu'un développement théorique accru des classifications de mobilité fondées sur les flux. L'ensemble des articles souligne la nature structurelle des inégalités de transport liées au genre et met en évidence l'importance d'intégrer des outils analytiques sensibles au genre dans la théorie comme dans la pratique.

ABSTRACT

This thesis proposes gender-centred analytical approaches, responding to the persisting need for methods capable of revealing how mobility systems differently shape the experiences of women and men. Using mostly publicly available datasets and a diverse suite of statistical and spatial techniques, the research examines how transport services, land use patterns, and socio-economic characteristics interact to produce gendered mobility outcomes. Across four articles, this thesis demonstrates that gender is embedded throughout the transport system: in travel behaviour, in the spatial organization of movement flows, in the access to opportunities, and in the attitudes and perceptions that shape modal choices.

The first article investigates gender differences in transport poverty in Canadian metropolitan areas. Using census data (2016) and publicly available spatial access measures (2022), it applies population-weighted indicators to compare levels of transport poverty, marginalization, and inaccessibility between women and men. Results show that women experience significantly higher transport poverty and marginalization, while they also experience less inaccessibility than men. Local Indicators of Spatial Association (LISA) reveal spatial nuances, identifying areas where high concentrations of women coincide with heightened transport disadvantage. These results demonstrate that the gender dimension of transport poverty is both measurable and spatially patterned, offering clear implications for targeted interventions.

The second article uses Montréal's Origin-Destination Survey (2018) to examine gendered differences in distance travelled and destination patterns. Through linear regression with bootstrapping, it is found that women travel shorter distances than men, and that the presence of children in the household disproportionately affects women's travel distances. The gender gap narrows in monoparental and middle-income households, suggesting that household structure and economic context mediate gendered mobility. Spatial analyses using LISA reveal that women travel more frequently to suburban areas for work, care, and leisure, while men's destinations are more concentrated in central areas.

The third article develops a spatially-aware classification of mobility flows per gender using Hierarchical Link Clustering (HLC). By classifying Montréal's origin-destination (2018) flows into movement types and modelling their explanatory factors, the analysis shows that women's flows are more likely to take place locally or be spatially elongated and multi-directional, reflecting

a combination of neighbourhood-based activities and longer trips. This study also finds that movement types manifest differently across the city for women and men, particularly in the suburban on-island areas (north) where women's elongated and multidirectional flows are concentrated. Regression results indicate that women's movement types relate to socio-economic factors, whereas men's are more strongly related to land use and transport services.

The fourth article explores gender differences in attitudes toward transport modes and their relationship to travel dissonance, meaning a mismatch between their preferred and their actually used travel mode. Using the 2023 Montréal Segmentation Survey, a survey of travellers in the Montréal region, this study applies factor analysis and multinomial logit modelling to examine how perceptions and socio-economic characteristics shape travel dissonance. The results show that women place greater emphasis on affective and efficiency-related attributes when evaluating transport modes, and that they hold more mixed opinions about particular travel modes overall. Men, by contrast, tend to evaluate most modes positively, with the exception of the bus. The analysis also finds that women's travel dissonance is more strongly explained by socio-economic factors, while men's is more influenced by attitudes and perceptions.

Some limitations are discussed: datasets lacking spatial granularity and categorical detail necessary to fully capture gendered mobility patterns, and the absence of sufficient data on non-binary individuals among them. These limitations point to clear directions for future research, including finer-grained spatial analyses of care-related mobility, deeper investigation into the relationship between work destinations and household task negotiation, and further theoretical development of flow-based mobility classifications. The articles underscore the structural nature of gendered transport inequalities and highlight the importance of integrating gender-aware analytical tools into both theory and practice.

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LISTE OF SYMBOLS AND ABBREVIATIONS

ARTM	Autorité Régionale de Transport Métropolitain
CA	Census Agglomeration (census geography)
CBD	Central Business District
CD	Census Division (census geography)
CMA	Census Metropolitan Area (census geography)
CT	Census Tract (census geography)
DA	Dissemination Area (census geography)
DB	Dissemination Block (census geography)
HLC	Hierarchical Link Clustering
OD	Origin-Destination
PT	Public Transport
RA	Research Article
TP	Transport Poverty
TRPOV	Transport Poverty Index
TRPOV-R	Transport Poverty Index Ranking

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CHAPTER 1: INTRODUCTION

1.1 Context

A body of knowledge has been built in transportation and mobility research about women's travel, but this lens is not yet mainstream among researchers and practitioners. The differences revealed between the daily mobility patterns of men and women in existing research suggests that considering the gender gap in planning and policy is vital for developing fair and inclusive transportation systems responsive to the needs and constraints of the entire population (D'Agostino et al., 2024). Women tend to make shorter trips, to complete more trips, to perform more trip chaining mixing work and care tasks, and to use public transport more than men (Pirra et al., 2021). Nevertheless, transport planning has traditionally adopted a gender-neutral approach, which obscures the differences between men and women's travel behaviour (Babbar et al., 2022). For example, a recent study in the UK showed that 46% of transport professionals do not consider gender in their day-to-day work (Brooks et al., 2023). In the EU, only around 22% of transport workers are women (Mejia-Dorantes, 2019). In research, gender is often relegated to a control variable, with broader epistemological and methodological considerations absent (e.g., Alousi-Jones et al., 2025; Ye et al., 2020).

The existing body of knowledge extends from the 1970s until today, including the seminal notions of the importance of considering gender in transport (Rosenbloom, 1978a, 2005) within a feminist agenda (Buiten, 2007), and the influence of women in achieving a sustainable transport agenda (Kronsell et al., 2016). Other areas previously researched are comparisons of women's transport conditions between high and low-income countries (Rosenbloom & Plessis-Fraissard, 2010); the relation between gender, the built environment, and transport patterns (Clifton & Dill, 2005; Handy, 1996, 2006; McDonald, 2005); gender differences in psychosocial aspects, attitudes, and opinions in relation to transport behaviour (Fu & Juan, 2017; Handy, 1996; Shirgaokar & Lanyi-Bennett, 2020); and mobility practices and strategies in the face of safety concerns (Lindkvist, 2024). Additionally, innovative approaches have been tested to understand the complexity of gendered mobility strategies, like combining quantitative information from travel surveys with ethnographies (Jirón et al., 2020). In the perspective of this body of work, this thesis expands on and revisits some of these topics to build on gaps left by previous research, offering an updated picture of different topics in transport from the perspective of gender.

The gender-neutral approach leads to a mismatch between women's mobility needs and the provision of transport service and infrastructure. For example, safety and access to employment are central to women's mobility experiences (Hanson, 2010), and although women's distinct travel patterns – particularly the balance of care and work trips – are well known, transport planning practice has traditionally focused on commute trips during peak hours, traditionally performed more by men (Brooks et al., 2023). Recent research tends to suggest that this trend has changed little over the past two decades (Uteng, 2021).

Looking more closely at gendered mobility, Akyelken (2020) reminds us that women's mobility practices and needs are shaped by a complex web of interdependencies, many of which lie outside the transport sector, such as social policies that reinforce structural inequalities. In this sense, Loukaitou-Sideris (2016) identifies four types of transport-related limitations faced by women: cultural (e.g., religious norms, caregiving responsibilities), economic (e.g., limited financial resources), physical (e.g., car-oriented urban form, poor pedestrian infrastructure), and psychological (e.g., fear and perceived insecurity). Despite the growing body of research on gender and transport, a gap remains regarding the influence of spatial and socio-cultural constructs on gendered mobility (Hidayati et al., 2020).

From a methodological standpoint, there are critical challenges to demonstrating and examining the gendered, non-neutral nature of travel behaviour, including the routine collection of gender data, access to this data, and the use of analytical methods suitable to revealing differences in travel between genders (Uteng, 2021). A recent review of the literature found that one key methodological shortcoming in studying women's mobility is that commonly-used quantitative methods fail to describe spatial-temporal variability, especially in urban areas, though this is a key point of divergence between men and women's travel behaviour (D'Agostino et al., 2024). Other studies highlight the growing need to understand the role of attitudes and psychological factors that shape women's travel (S. Luo & He, 2021a; Yeganeh et al., 2025), and the resultant need to collect appropriate data and to analyze these aspects of mobility. In this context, there is a need to explore avenues for adapting or combining methodologies for studying gendered mobility, to better inform transport planning and policy (Babbar et al., 2022a). Developing methods for examining gender differences in transport is needed.

1.2 Research Objectives and Questions

This thesis adopts gender as an overarching analytical lens, as conceptualized by Law (1999) and Sanchez de Madriaga (2013), with which to examine the relationships between individual characteristics, land use, transport systems, and travel behaviour, with the aim of uncovering systematic differences in mobility-related phenomena between men and women. The objective is to propose robust, gender-centred analytical approaches that can meaningfully inform transport planning and support human-centred research. This responds directly to the limitations of traditional gender-blind planning (Brooks et al., 2023), which assumes that all users share the same needs, constraints, and mobility patterns. In practice, men and women navigate the city differently, face distinct barriers, and hold different responsibilities. When these differences are ignored, transport systems and urban environments inevitably privilege certain groups while disadvantaging others. In this context, the research framework is oriented towards adapting and applying methods suitable for revealing gendered transport patterns using secondary data sources, which are large-scale and often publicly available, supporting reproducible and adaptable research. In line with this, the overarching goal of this thesis is the following: **to adapt and combine quantitative and spatial methods to propose robust, multidimensional, and multi-perspective gender-centered analytical approaches to better inform equitable transport planning**.

To achieve this goal, this thesis seeks to address the following research questions (RQ):

- Research Question 1: What are the differences in transport patterns between men and women? And how are these patterns expressed in space?
- Research Question 2: In what ways do land use and transport systems, together with individual characteristics, result in gendered transport patterns?
- Research Question 3: How can existing data can be leveraged to better understand gender differences in transport?

The aim of this thesis is not to answer each of these questions comprehensively, as this would imply an extent beyond what is approachable in a PhD timeframe. Rather, these three interrelated questions serve as a multidimensional and multi-perspective framework to approach the incorporation of gender into transport research and planning. RQ1 and RQ2 were developed to enable the assessment of gendered mobilities, and RQ3 emerged as a central question that serves as a pillar for the design of appropriate, gender explicit, methods in research and planning. The

four articles of the thesis sought to develop approaches that contribute to answering these questions. As a thesis in transport engineering, its objective is oriented towards the development of methodologies more than to the advancement of gender theories as a social topic.

1.3 Thesis Structure

The following chapter (Chapter 2) contains a general review of the literature, highlights the research gaps, and describes how this thesis contributes to filling these gaps. Chapter 3 presents the general methodological framework and describes the datasets and modelling approaches used in the thesis. Chapter 4 through 7 then correspond to the four scientific research articles that compose this thesis:

- Chapter 4 corresponds to Article 1: Are Women More Transport Poor Than Men? Exploring Gender Discrepancies in Transport Poverty (published in Findings, August 2025). This chapter is supported by the paper presented in Appendix A (submitted to Sustainable Transport and Livability, revisions requested, February 2026).
- Chapter 5 presents Article 2, the second published article of this thesis: Going the distance: Gender differences in travel in Montréal, Canada (published in Journal of Transport Geography, June 2024).
- Chapter 6 describes Article 3, the article is titled: Human-Centred Mobility Flow Classification: Differences in Travel Patterns between Men and Women (submitted to Applied Geography, August 2025).
- Chapter 7 has the last article, for Article 4: Exploring the relationship between gender, travel dissonance, and attitudes in Montréal, Canada (submitted to Travel Behaviour and Society, March 2026).

Chapter 8 synthesizes and discusses the key findings of this thesis, structured around the three RQ, the methods used, limitations, and avenues for future research. Chapter 9 concludes by summarizing the contents of the thesis and its articles.

CHAPTER 2: LITERATURE REVIEW

This literature review introduces a general outlook about the state of knowledge in gender and transport research in section 2.1, continuing with an overview of research findings on gendered mobilities (section 2.2). Then, the relationship between gender and travel behaviour is outlined in section 2.3, with a focus on travel time, distance, purpose, and mode. After, section 2.4 reviews specific topics (transport poverty and travel dissonance) where a misalignment between women's needs and the mobility landscape has been identified. Section 2.5 reviews the methodologies used for gender research in transportation in quantitative, qualitative, and mixed methods. Then, section 2.6 synthesizes the research gaps identified and relates them to the articles of this thesis.

It is important to note that each article presented in this thesis (Chapter 4 to 7 and Appendix A) provides an in-depth review of the literature. This chapter, therefore, aims to provide a structured and comprehensive overview of the current state of knowledge of gender and transport, rather than a detailed review of each topic.

2.1 Gender in Transport Policy

Cities, as living organisms, are formed by the underlying rules of the population that inhabits and builds them (Hillier, 1997). They are shaped by the gendered embodiment and social reality of daily routines, and they function in the production, consumption, and reproduction of gender norms and identities (Jarvis et al., 2009), as gender relations permeate all aspects of social activity (England, 1991). Although this is a pervasive dynamic, gender as a framework for planning and design is not mainstream in urban planning processes. While to an extent the importance of considering gender in planning is now recognized, it is necessary to consider gender more systematically in urban research (Jarvis et al., 2009).

Women significantly contribute to urban prosperity through a wide range of paid and unpaid labour, but still often face challenges in terms of equitable access to "decent" work, human capital acquisition, physical and financial assets, intra-urban mobility, personal safety and security, and representation in formal structures of urban governance (Chant, 2013; Noor & Iamtrakul, 2023). This situation is present in all aspects of the urban sphere, including in transport systems and the mobility landscape more broadly.

Policy responses towards women's mobility needs have been uneven due to sociocultural norms, physical/economic obstacles, and policymakers' limited comprehension of and effective response to women's mobility needs (Loukaitou-Sideris, 2016). In this respect, Sanchez de Madriaga (2013) points out that research and public policy tend to unintentionally and unconsciously privilege the particular experience of a specific group in power, granting this group's experience the character of a universal norm. In the case of transport, the realities of adult middle- or upper-middle-class white men, in good health, with the capacity to influence planning decisions, came to guide the developing of the mobility landscape (Loukaitou-Sideris, 2016; Sanchez de Madriaga, 2013). Consequently, their needs have been prioritized, consciously or unconsciously, and their needs have been assumed to represent the needs of the general population. For example, public transport projects that privilege rapid inter-city transit have historically been favoured, but have failed to improve intra-city, non-motorized means of transport that are critical to many women, such as local roads, buses, and bus stops (Loukaitou-Sideris, 2016). As such, policies which assume that women and men have the same travel patterns and have equal access to different modes of transport lead to overlooking women's needs and constraining their capacity to engage fully in daily activities, and to access social and economic opportunities (Ng & Acker, 2018).

2.2 Gendered Mobilities

Before reviewing the literature on travel behaviour (Section 2.3), this section first touches on transport from the perspective of gender roles and their underlying power relations, in order to contextualize the topic. From the perspective of the Social Role Theory, gender stereotypes and differences in behaviour stem from the social roles that society assigns to men and women; in this framing, city-making both reflects and reinforces the dynamics of gender, race, and class relations, sustaining the dominance of certain groups over others and perpetuating human inequality (Sacchi et al., 2025). From this theory, when speaking about gender in the urban sphere and with regards to movement (transport), a relatively dichotomous dynamic is often conceptualized: women are associated with stillness, private space, routine, the familiar, and suburban spaces; while men are associated with movement, public space, expansion, excitement, centrality, and unknowingness (Hanson, 2010; Law, 1999). This vision has guided, or at least permeated, the negotiation of spaces and services in the city, generating gaps between genders (Sacchi et al., 2025). Additionally, home and work tend to be seen as separate spheres of reproduction and production of both economic

revenue and social practices (Kwan, 1999b). In this form of city-making, different social groups do not enjoy of equal levels of mobility and accessibility; women in particular often face significant mobility challenges that decrease their accessibility to urban resources and opportunities, which can be seen as a spatial expression of patriarchy (Loukaitou-Sideris, 2016). In this way, patriarchy reproduces spatial patterns of domination through transportation planning. To date, the study of gender differences has shed light on some key aspects that condition women's travel behaviour. For example, a key research area addressed the characteristics of women's travel to and from employment, thereby highlighting differentiated commute needs (Law, 1999). Generally speaking, most studies find that, compared to men, women tend to work closer to home and in a more enclosed radius of activity (discussed further in section 2.3) (Hanson, 2010).

Another key stream of research, referred to as mobilities of care, has emphasized how trips to work have taken attention from other aspects of travel and urban life, such as non-work trips, trips by non-employed people (like older women), and potential trips that are not made (Law, 1999). Although some non-work trips are recognized in planning (like education, health, sport, and cultural services), services for the care of dependents are still commonly not comprehensively taken into account in data collection, analysis, policy, and planning (Sanchez de Madriaga, 2013). In fact, non-work trips for purposes such as recreation, entertainment, social contact with friends and family, political involvement, and personal and health care might be more frequent than work-related trips for some groups, and may also be more important than work trips in contributing to individual perceptions of mobility (Law, 1999). Although the gap is reducing, women remain the primary caregivers for children and elderly parents and are mostly responsible for domestic chores in the U.S. (Milkie et al., 2025) and in Canada (Li et al., 2022). Therefore, they are more likely to experience a reduction of time for discretionary activities, the need to perform trip chaining (a succession of short trips, often for household errands), and a reduction in access to well-paid jobs far from home (Loukaitou-Sideris, 2016). For these reasons, Sanchez de Madariaga (2013) highlights the need for a definition of care trips as a separate category from other, non-work trips: unpaid labour performed by adults for children and other dependents, including labour related to the upkeep of a household. The author also emphasizes the need to quantify these trips, which, along with other non-work trips, when put together, might represent a portion of travel as large as, if not larger than, work trips. The fact that transport surveying efforts often still lack a separate and explicit category for care trips implies a perpetuation of patterns in which women's needs related

to care are not visible nor catered to, given that, despite the proportion of care and other non-work trips, transport systems are predominantly planned to support the home/work journey (Sanchez de Madriaga, 2013).

Perceptual and psychological barriers also play a role in constraining women's movement. For example, parents are more likely to give their sons a larger latitude for movement across city spaces than their daughters, who are perceived as more susceptible to the threat of 'stranger danger', resulting in girls tending to be more confined in their mobility (Loukaitou-Sideris, 2016). This is culturally dependent, and has been found in countries like the U.S., Italy, South Africa and Israel (B. Shaw et al., 2015), whereas in places like Japan, Canada, and the Netherlands there has been little to no statistical difference for gender on the possibility of independent travel (Cervesato & Waygood, 2019; van den Berg et al., 2020; Waygood & Kitamura, 2009). However, the experience of more confined mobility may transcend childhood and remain in adulthood, resulting in women's under-representation in public spaces, as well as their more limited use of cycling in comparison to men (Loukaitou-Sideris, 2016; Ravensbergen et al., 2019). Nonetheless, transport and urban planning can mediate these differences. In a study of nocturnal immobility in China, Zhang et al. (2022) found that in the inner cities of Wuhan and Urumqi, where land use is diverse, the built environment is compact, and the population is dense, women are less likely to have a fear of nocturnal travel compared with those living in the suburbs. The authors suggest that promoting land use density and diversity, encouraging safety-oriented urban design, and enhancing the nocturnal police force and security facilities in suburban areas and in key transport nodes (i.e., backstreets, underpasses, and outlying bus stations) can mitigate women's fear-induced immobility and reduce the social exclusion of fear-vulnerable groups.

In view of the complexity of factors interacting to condition women's trips, applying gender as an analytical framework in transport (Law, 1999; Sanchez de Madriaga, 2013) would allow for seeing gendered variations in mobility choices (travel demand), mobility (or travel) behaviour (purpose, time, distance, duration), and the perceptions and experiences of mobility.

2.3 Travel Behaviour

Gender and travel behaviour are interrelated, and their relationship has changed over time. The gender gap of travel for care trips is changing (McQuaid & Chen, 2012), while disruptive events like COVID-19 (Smith et al., 2025), the rise of online shopping (Jaller & Pahwa, 2020), and social

media interactions (Vasquez-Henriquez et al., 2020) modify the relationship between the household, travel, and the city. As society changes, different perspectives, including a gendered lens, are needed to explore how people travel, and how land use and transport systems meet people's needs. Transport patterns disaggregated by gender indicate that women and men use the city differently in terms of trip time, location, activities, and mode of travel (Levy, 2013). In line with this, and to provide an overview of travel behaviour, this section will focus on these four characteristics: trip time, trip distance, trip purpose, and mode. Specifically, this review highlights the key gender differences as well as the determinants underlying these differences. It is important to remember that travel is a multivariate phenomenon, which is why descriptions about 'categories' of travel characteristics are often intertwined with one another, and with other influencing or explanatory factors.

2.3.1 Time

The duration of trips varies according to the mode chosen and the purpose of the trip; however, the dominant trend is that men tend to spend more time traveling than women. Starting with work trips, in Northern California Goddard et al. (2006) find that men tend to work more days per week and have longer commutes, in terms of time and distance, than women. Working men in urban Canadian regions travel approximately 15 minutes more than working women (Sweet & Kanaroglou, 2016). Fan (2017) finds that, in the U.S., women's shorter work travel time is only statistically observable in households where there is a couple with children. Contrary to work travel time, women tend to spend more travel time for household-care tasks (Shirgaokar & Lanyi-Bennett, 2020). In fact, the presence of children, and more specifically of young children (age under 15), is one of the heaviest determinants of gender differences in travel time (Chakrabarti & Joh, 2019; Shirgaokar & Lanyi-Bennett, 2020). While the gender difference in household-care travel time is sensitive to parenthood (Fan, 2017; Shirgaokar & Lanyi-Bennett, 2020), it is not sensitive to spousal/partner presence; even when a woman is the sole income earner in a coupled household with children, she still travels shorter for work and longer for household care (Fan, 2017). Overall, trips made by men are typically longer (and they make more work trips), but women spend more time traveling for care trips.

There are other factors intervening in the gender gap of travel time, such as race. Crane & Takahashi (2009) find, using national data from the U.S., that Black and Hispanic women commute

longer than Black and Hispanic men by bus. Conversely, in years when child-care is an activity they are involved in, Black and Hispanic women tend to have much shorter commutes than men in the same age groups. Black women have longer commute times and lower levels of spatial containment than either White or Latina women (McLafferty & Preston, 1992). However, more research is necessary to assess the current state of the intersectional effect of race and gender on travel time, as existing research is dated.

As mentioned earlier, mode choice is also related to travel time differences. In an analysis of 19 cities from 13 countries in both the Global North and South, working women are found to have a higher level of time spent in active travel modes than men: women spend 62% of their active travel time by walking for the entire duration of the trip, while this figure is 54% for men (Goel et al., 2022). Similarly, Uteng (2021) confirms that women generally walk more than men to perform daily activities.

2.3.2 Distance

As with time, the trend is that travel distances are longer for men than for women (Crane, 2007; Ng & Acker, 2018). Crane (2007) highlights that the gender gap extends across differences in income, marital status, age, housing tenure, parenthood, and location within the metropolitan area, and perhaps also across occupation. These characteristics may be gender-specific and not unique to the city type, geographical location, or level of economic development (Ng & Acker, 2018). Some nuances are added by other authors, who find that travel behaviour trends of men and women could slowly converge as women work more and attain higher levels of education than in the past, as recent studies have shown that younger women are traveling further as they age, and men are driving less (Loukaitou-Sideris, 2016; Ng & Acker, 2018). However, while mobility is usually seen as empowering for most individuals, a sort of ‘hypermobility’ can be constraining to women, like suburban mothers, who are constantly behind the wheel of their cars, transporting their children to various destinations (Loukaitou-Sideris, 2016). In this respect, Sanchez de Madriaga (2013) points out that short pedestrian trips (less than 1 km), frequently made by women in their daily routines attending to the family and the home, are often intentionally omitted in many transport surveys because they are not considered to be relevant for infrastructure policymaking. Nevertheless, they are important in understanding the mobility of care, women’s travel, and trip-chaining, as, for example, among workers, women stop on the way home significantly more often than do men

(Goddard et al., 2006). To support this point, it was found that married men have longer commutes than single men, but married women have shorter trips than single women, probably because marriage leaves the average woman with additional family responsibilities, encouraging greater proximity between work and home (Crane, 2007). In fact, Fan (2017) finds that mothers only considered job opportunities close to home.

In terms of the relationship between trip distance and travel mode, men report that they drive significantly more miles than women, but women with higher levels of education or children under 18 drive relatively longer distances than men (Goddard et al., 2006). As for biking, women are more likely to make multiple bike-share circle trips chains than men (multiple circle trips being trip chains that start from an origin to a single destination and then ends at the same origin, made several times), on weekdays in particular (Zhao et al., 2015).

Other factors, including socio-economic status, are found to affect women's daily mobility. According to the review by D'Agostino et. al (2024), women with high wages are more likely to live close to city centres, where most workplaces are located, allowing them to commute shorter distances and taking less time than low-wage earners (Iwata & Tamada, 2013). The same review also considers ethnicity as influencing travel distance, citing McLafferty and Preston (2019), who find that white women travelled shorter distances in the New York City area to perform their higher-wage jobs than Black, Hispanic, and Asian female workers.

2.3.3 Purpose

In accordance with the trends for time and distance, in travel for all purposes, not just for work, women also use the car less and drive fewer miles than men do, even when education, income, and marital status are held constant (Hanson, 2010). A national study in the U.S. by Bernardo et al. (2015) finds that while women in general participate less in recreational and physical activities, perhaps in part because of the time investment in mobility of care, young women (30 years or younger) participate more in out-of-home social activities compared with men, implying that out-of-home socializing may be appealing to women as a means to relax after work and household maintenance activities.

In a study conducted in Canada, Sweet & Kanaroglou (2016) report modelling results that indicate that having children incurs significant time use obligations on women but not on men, while descriptive statistics indicate significant time use differences between men and women: men work

and engage in sports and hobbies more, while women care for children, fulfill domestic responsibilities, and shop more. Women are much more likely to undertake maintenance and out-of-home shopping activities (Bernardo et al., 2015). Along this line, trips for household maintenance, also known as care trips, have a polygonal spatial pattern, are shorter in comparison to employment trips, and cover a smaller area closer to home (Sanchez de Madriaga, 2013). The author highlights that these trips are made more often by women than by men, using public transport and on foot. Notably, women's professional and socio-economic status strongly affects their patterns of mobility of care, as low-wage earning women usually have to perform more care tasks (D'Agostino et al., 2024).

Among care trips, some of the most common are trips for dropping off or picking up members of the household to or from their activities, where mothers are still more likely than fathers to chauffeur their children to school and other purposes, a fact which supports that the division of household chauffeuring duties is gendered (Hsu & Saphores, 2014; Motte-Baumvol et al., 2017). The women-men chauffeuring gap is larger, and falls more disproportionately on women, in households with more children (under 11 years) and adolescents (11-15 years), and with more cars; this gap closes the more the woman earns relative to the man, evidencing that the household division of chauffeuring duties correlates with gender income earning potential (Boarnet & Hsu, 2015). Mothers travel more in the afternoon than do childless women, because child-related activities take place after school hours (Eyer & Ferreira, 2015). As for caring trips made on foot, with regards to strolling a baby or toddler, these trips are made more times per month by women than men, while being a renter rather than a home owner reduces the strolling frequency for women but not for men (Goddard et al., 2006). The same study indicates that safety perception increases the strolling frequency for women but not for men; for men, having more leisure businesses within 1.6 km of home, and having physical activity options in the neighbourhood, increase the strolling frequency, variables which have no effect for women. In line with these previous results, Ravensbergen et al. (2022) find that, in Montréal, women perform more care trips than do men, and the presence of children in the household widens this gap; car use and walking are more frequently used for care trips, and women use public transport more for care purposes than do men. Ravensbergen et al. (2020) also find that in Toronto, bicycling is usually perceived as difficult for transporting big groceries and children, but for small amounts of groceries and trip-chaining, it was usually perceived as convenient.

Most notably, after considering the types of trips and their length, when putting all mobility of care trips together, they may represent a significant share of total trips, to an extent approaching work-related trips, indicating their importance in the design of transportation systems that are more responsive to users' needs (Sanchez de Madriaga, 2013).

2.3.4 Mode

Gender appears to be a more robust determinant of mode choice than either age or income (Ng & Acker, 2018), a fact that is present also in rural spaces (Miralles-Guasch et al., 2016). In terms of travel patterns, women conduct a far larger proportion of their travel on foot than do men; whereas with bicycling trips, the trend is far more variable. For example, in Canadian and New Zealand cities, it has been found that only 19-30% of bicycling trips are made by women (Mitra et al., 2016; C. Shaw & Russell, 2017), while in Finland, Germany, and the Netherlands, women's bike share is near 50% (Goel et al., 2022). Women use family cars less for job-related duties, especially in households with more driving license holders than cars, but also in families with as many cars as driving license holders (D'Agostino et al., 2024). Women use public transport modes more, over driving a car (Uteng, 2021). Interestingly, since women have more complicated travel patterns, they also tend to prefer more flexible modes, which implies an opportunity to cater to women's mobility needs through emerging trends in flexible mobility, such as shared mobility or mobility-as-a-service (Ng & Acker, 2018). Further, underprivileged and immigrant women are more transit-dependent than men; when only one car exists in the family, men are more likely to use it for work, even if both spouses are employed (Loukaitou-Sideris, 2016). However, women's use of public transport can be affected by impediments in the structural design of buses, trains, and trams (think of mothers with strollers in buses with stairs), which is why understanding the needs of the most vulnerable users is necessary for appropriate service provision (Ng & Acker, 2018).

As for social-household determinants for mode choice for women, children under 16 years of age seem to be a strong predictor for automobile dependence, as in the U.S., mothers of children in this group have significantly higher vehicle miles driven, and 42% of them drive a pickup truck, minivan, or SUV (Goddard et al., 2006). When a couple does not live in their ideal location, in non-urban settings, men are less affected by the residential environment and rely more on personal preferences and partners' travel demands and preferences for daily travel, demonstrating a low frequency of car use while their cycling and train use were high; moreover, couples in this housing

situation preferred walking (Gao et al., 2022). D'Agostino et al. (2024) point out that the gender gap in car usage is declining, but that scholars should be cautious in interpreting this reduction as an unquestioned positive signal because it may relate to other dimensions of mobility, like mobility of care or a distant job location while living in the suburbs. Miralles-Guasch et al. (2016), in a study in urban and rural Spain, found that despite the different territorial realities, gender explains mode choice much better than other variables, such as age or geographical factors. The authors also point out that within the paradigm of sustainability, and specifically its environmental and social dimensions, it is essential to analyze mobility models in different geographical contexts, such as rural and urban settings.

A study that examines the factors affecting people's likelihood of being aware of the implementation of the Montréal Réseau Express Vélo (REV), a network of bike infrastructure, revealed that women, especially young women, are less likely to be aware of REV than men (Lam et al., 2024)**.** Also, non-white, non-francophone women are less likely to be aware of the project than men. Meanwhile, another study in the same city found that women, and especially young women, are less likely than men to have an intention to use light-rail transit (LRT) (Villafuerte-Diaz et al., 2023). The same study also found that recent immigrant women have far more intention to use the LRT than non-immigrant women, and this was not significant for men.

2.4 (Mis)alignment between land use and transport systems, and women's needs

The literature on travel behaviour reveals clear gender differences in trip patterns. Given the marginalization of women's needs in traditional planning approaches, land use and transport systems do not always align with women's needs. Two key considerations addressed in this thesis are transport poverty and travel dissonance.

2.4.1 Transport Poverty

Lucas et al. (2016) presents a working definition of transport poverty, claiming that an individual is transport poor if, in order to satisfy their basic daily activity needs, they are affected by one of the following conditions: there is no transport option available that is suited to the individual's capabilities; the existing transport options do not reach destinations necessary to fulfill daily needs; the individual cannot meet transport costs; it is necessary to spend an excessive amount of time

traveling; or they are exposed to unsafe or unhealthy conditions while traveling. By this broad definition, it is worth noting the interaction between land use and transport characteristics, such as transport availability and location of destinations, and personal characteristics, such as the capacity to afford to travel, personal capabilities, etc. Hence, transport poverty is generally described as the direct and indirect interaction between social disadvantage and transport disadvantage (Lucas, 2012).

Transport poverty can lead to transport-related social exclusion, meaning an inability to participate in society (Lucas, 2012) caused at least partly by transport disadvantage. Social disadvantage refers to a multi-causal phenomenon that results in low levels of access to, participation in, and autonomy with regard to, economic life, political life, social life, cultural life, and health (Schwanen et al., 2015). On the other hand, transport disadvantage can be understood as a complex, multidimensional construct brought about by the interaction between land use patterns, the transport system, and individual circumstances (Currie & Delbosc, 2011). Given that individual circumstances are already considered in the social disadvantage component, for this work, we will understand transport disadvantage as the interaction between land use patterns and the transport system.

While there is ample research dedicated to the interaction between transport poverty and gender in low-income countries (Faiz et al., 2020; Iqbal et al., 2020; A. Roy, 2011), research is sparse in high-income ones. In both cases, high- and low-income countries, studies point toward gender-specific factors associated with transport poverty. Among the few studies conducted in Canada, Palm et al. (2024) find that women are among the groups most prone to having unmet transportation needs. These results warrant the need to further explore transport poverty from a gender-aware perspective and in the Global North context.

2.4.2 Travel Dissonance

Dissonance is a mismatch between opinions or values (that can be called overall attitudes) and behaviours (Festinger, 1957). As demonstrated by De Vos and Sigleton (2020a), it is a useful framework to study travel behaviour, as the dissonance between attitudes and behaviours can result in feelings of discomfort, which people will try to reduce by changing either their attitudes or their behaviour, and has been studied since the 1990s, for example in Schwanen & Mokhtarian (1998). As such, McCarthy et al. (2023) find that dissonant travellers are more likely to change their mode

than are consonant travellers. Investigating the relationships between attitudes towards travel mode choices or residential location choices and mobility behaviours can therefore support the development of land use and transport systems that reduce dissonance and support the sustainable and durable use of public and active transport modes.

A substantial body of research has looked at travel dissonance in general, but gender-specific travel dissonance has been studied less. While a few studies have highlighted gender differences in relation to travel dissonance, findings are quite sparse and diverse. In Ganyu, China, it has been found that men with a preference for car use are more inclined to work in suburban environments, while women who do not prefer car use tend to work in central urban areas (Hu et al., 2024). Another study in Ganyu showed that in urban neighbourhoods, single mothers who do not like e-bikes and young men who prefer the car are dissonant, and that income and education levels influence attitudes towards sustainable travel modes (Hu & Ettema, 2023). In Nagoya, Japan, men showed the dissonance of a preference towards cycling when they were proximate to the subway and perceived it to be safe, while women showed dissonance towards walking when their distance to transit stations was longer (Gao et al., 2026). In Porto, Portugal, men had significantly higher average car dependence, expressed a greater need for control and also more positive attitudes about public transport. Women were more sensitive to travel stress, travel cost, and have more desire to change modes (Beirão & Cabral, 2008). Recent research on gendered opinions about particular transport modes has found that women are more concerned about the comfort of transit environments (e.g., temperature, crowdedness, and safety, especially at night), and men tend to be more interested in transit e-payment services and reporting traffic incidents (S. Luo & He, 2021b). Considering the diversity of findings that touch upon a variety of factors, more efforts are warranted to deepen our understanding of each of these factors (and their interactions) and to develop a unified body of knowledge.

It is also worth noting that this gender-specific body of literature about general travel behaviour and dissonance is not centred in North America. In the North American context, recent studies have assessed attitudes towards transport alternatives in the process of implementation with a consideration for gender disparities (Lam et al., 2024; Villafuerte-Diaz et al., 2023). Gender-focused studies that analyzed travel dissonance as such in Canada were not found.

2.5 Methodologies used in gender and transport research

Since the overarching goal of this thesis is to develop gender-based analytical approaches, this section provides an overview of existing methods that have been applied in gender and transport studies. The selected papers provide an overview of the main techniques/datasets used to study transport from a gender perspective. The studies were divided into quantitative, qualitative, and mixed methodologies to organize how methods respond to objectives in a structured manner.

2.5.1 Quantitative methods

Quantitative methodologies help identify broad patterns emerging from large-scale datasets. In gender and transport research, three main types of quantitative analysis are generally used. These three types vary in terms of their complexity and contribute to achieving different objectives. A list of the reviewed papers, techniques, datasets, and objectives can be found in **Table 2.1.**

The first type of quantitative analysis consists of exploratory data analysis and descriptive statistics, to get a first sense of the data and to describe general patterns (e.g., Crane and Takahashi (2009); Rosenbloom (1978b)). As an example, Crane and Takahashi (2009) aim at investigating the longitudinal trends of the gender gap in commuting time, and its relation to age and ethnicity. The method of exploratory analysis and descriptive statistics was effective in describing a timeline of the evolution of commuting times and the split by demographic variables, but could not assert statistically significant differences in the trends.

The second type of analysis consists of bivariate analyses which aims to assess the relationships between variables through descriptive and statistical tests. For example, Goddard et al. (2006) use cross-tabulations with chi-square tests and independent sample t-tests to explore interactions between travel and neighbourhood characteristics from a gender lens. After splitting by gender, they analyze a set of travel behaviour and neighbourhood attitude variables by gender to find statistically significant differences in how men and women behave and perceive their environment. They then analyze women's trips in more detail, comparing homes with and without children. They find that men drive significantly more miles than women, that women who work stop on the way home significantly more often than men, and that women in traditional neighbourhoods walk significantly more than women in suburban neighbourhoods. Similarly, Zhao et al. (2015), using Z-score analysis, visual analytic techniques, and Chi statistics, explore the variation of bike sharing

travel time and trip chains from a gender perspective. Overall, these analyses are useful in describing general trends in the differences between men and women's travel patterns, by establishing the statistical significance between gender and a set of variables related to travel behaviour or land use.

The third type of analysis is multivariate analyses, implying statistical modelling with several variables. While bivariate analyses focus on two variables at a time, multivariate analysis controls for the interaction between several variables. A large variety of modelling techniques exist, with the most common ones used in transport and gender research being Ordinary Least Squares (OLS) regression, negative binomial models, and multivariate logit models. OLS allows for modelling the relation between a continuous variable and other explanatory variables, by minimizing the sum of square differences between the observed and predicted values. For example, to understand key differences in the relationship between neighbourhood characteristics and travel, Goddard et al. (2006) uses OLS after having conducted a series of bivariate analyses (described above). The authors use vehicle miles driven, frequency of walking to the store, and frequency of strolling trips as dependent variables, and socio-demographics, perceived neighbourhood characteristics, neighbourhood preferences, objective neighbourhood characteristics, and travel attitudes as independent categories, using gender as an interaction term. In doing so, the authors shed light on how gender mediates the relationships between travel behaviour (distance and frequency in different modes) and traditional versus suburban neighbourhoods. Negative binomial regressions are also commonly used, a technique which allows for modelling count data as the dependent variable. For instance, Boarnet and Hsu (2015) use this type of regression to compare non-work trip generation rates (number of trips per day) across genders and household types. Several types of logistic regression are also used. Logistic regressions are used when the dependent variable is categorical. Chakrabarti and Joh (2019) use binary logistic regressions to understand differences in travel behaviour between types of households (with or without children, and children being in certain age ranges), using household type as the dependent variable. Other techniques include principal component analysis (Gao et al., 2022), structural equation models (Sweet & Kanaroglou, 2016), path models (McLafferty & Preston, 1992), Tobit and beta regressions (Havet et al., 2021), and pooled log-linear regressions (Fan, 2017). Overall, multivariate modelling analyses enable understanding the influence of gender on a variable when controlling for a set of factors at once, by modelling the complexity of social life beyond the men versus women comparison.

As for the data used in quantitative analyses, regional or city travel surveys collected by agencies are commonly analyzed (Chakrabarti & Joh, 2019; Fan, 2017; Gao et al., 2022; Hsu & Saphores, 2014; Ng & Acker, 2018; Shirgaokar & Lanyi-Bennett, 2020; Tilley & Houston, 2016). Travel surveys offer a breadth of travel behaviour information, often along with some socio-demographic variables, and typically collected for a large and representative sample of the population. They allow for understanding travel behaviour differences between population groups, and tend to have geographically located information as well, which are vital in gender and transport analyses. They offer the potential for longitudinal analysis as well, as they are typically collected periodically. These datasets can have a level of bias, as some low-income populations may be harder to reach to be surveyed. Also, they may not ask questions about topics that may be of interest to a particular research project, especially from a gender perspective, such as information about safety, the perception of mobility, and mobility of care. Finally, they have limited spatial granularity, for the purposes of preserving respondent privacy, and the sample, although large, is sometimes limited for detailed spatial analyses.

Small travel surveys collected by researchers are another type of data for gender research (Goddard et al., 2006; Mandhani et al., 2021; Rosenbloom, 1978b). They offer precise information about the topic investigated, which makes them useful for gender research, as researchers can collect precise and detailed information aligned with their research questions. However, they can be costly and have a sample bias, which is why they are used more often in small-scale case studies.

Another type of dataset used is time use surveys (Bernardo et al., 2015; Fan, 2017), which are useful for gender research for understanding differences between men and women in time spent travelling compared to other activities of the day, and relating it to larger theories of responsibility burdens and mobility freedom for discretionary activities. However, travel information can be scarce and may only exist when linked to a specific activity. Also, there is no guarantee of spatially detailed information, or of travel behaviour information such as travel mode.

Census information, including microdata (McLafferty & Preston, Valerie, 2019; Sweet & Kanaroglou, 2016), offers a large amount of socio-demographic information. However, often, travel microdata is collected only for a sample of the population and only in relation to commute trips. This can be useful for gender research to investigate differences between genders related to

work trips, and their relation to an array of demographic variables. Another disadvantage, however, is that to preserve anonymity, trips are often aggregated to large spatial areas.

Another data source is smart-card based datasets (Zhao et al., 2015), where, for example, public transport system allow payment by smart-cards linked to particular users. They offer large data volume, and often precise locations, but usually have limited or no socio-demographic information, like gender. They also show only trips related to the public transport system, so the researcher has no information about other trips made with active modes or private vehicles.

Quantitative methodologies in gender and transport research range from simple descriptive analysis to complex multivariate modelling, each serving different analytical purposes. Although the information this research delivers is extremely useful for policymaking, it often leaves gaps about the mechanisms underlying these patterns or behaviours, therefore obscuring some possible solutions to shortcomings of public policies. Therefore, these methodologies must be adapted to more effectively uncover how gender and transport planning processes interact.

Table 2.1: Summary of selected quantitative studies on gender and transport.

Author	Year	Title	Objective	Place	Dataset	Methods			
						Exploratory and Bivariate Data Analysis	*Multivariate methods: Linear Models*	*Multivariate methods: Logit Models*	*Other Methods*
Rosenbloom, Sandra	1987	**The Impact of Growing Children on Their Parents' Travel Behaviour: A Comparative Analysis**	To analyze the extent to which non-economic variables (e.g., household and child-care responsibilities) explain and predict travel behaviour.	Netherlands, U.S., and France	Small-scale attitudinal surveys in each country	Summary statistics			
McLafferty, Sara Preston Valerie	1992	**Spatial Mismatch and Labour Market Segmentation for African-American and Latina Women**	To measure the effects of segmentation variables and transit mode on commuting time to determine the links between labour market segmentation and spatial mismatch.	New Jersey, U.S.	Census Public Use Microdata Sample New Jersey				Path model
Goddard, Tara Handy, Susan Cao, Xinyu Mokhtarian, Patricia	2006	**Voyage of the SS Minivan: Women's Travel Behaviour in Traditional and Suburban Neighbourhoods**	To investigate the relationship between neighbourhood characteristics and travel.	California, U.S.	Survey applied to eight Northern California neighbourhoods	Chi-square, independent t-tests	OLS, negative binominal		
Crane, Randall Takashi, Lois	2009	**Sex Changes Everything: The Recent Narrowing and Widening of Travel Differences by Gender**	To analyze national microdata covering 20 years to examine the influence of gender on travel and the relationship to demographic factors.	U.S.	U.S. American Housing Survey (AHS), a biannual survey of housing units using roughly the same sample in nine waves since 1985	Summary statistics			
Hsu, Hsin-Ping Saphores, Jean-Daniel	2014	**Impacts of parental gender and attitudes on children's school travel mode and parental chauffeuring behaviour: results for California based on the 2009 National Household Travel Survey**	To explore the factors associated with parental chauffeuring behaviour.	California, U.S.	National Household Travel Survey			Binary	

Table 2.1: Summary of selected quantitative studies on gender and transport. (continued)

Author	Year	Title	Objective	Place	Dataset	Methods			
						Exploratory and Bivariate Data Analysis	*Multivariate methods: Linear Models*	*Multivariate methods: Logit Models*	*Other Methods*
Bernardo, Christina, Paleti, Rajesh, Hoklas, Megan, Bhat, Chandra	2015	**An empirical investigation into the time-use and activity patterns of dual-earner couples with and without young children**	To examine the time-use patterns in work and non-work activities of individuals in dual-earner couple and nuclear family households.	U.S.	American Time Use Survey			Nested	
Boarnet, Marlon G. Hsu, Hsin-Ping	2015	**The gender gap in non-work travel: The relative roles of income earning potential and land use**	To examine if the within-household gender chauffeuring gap is associated with wage- or income-earning potential, socio-demographics, and land use variables.	Southern California, U.S.	Southern California Post-Census Regional Household Travel Survey	Independent t-tests	Negative binomial, censored-Tobit	Multivariate ordered	
Fan, Yingling	2017	**Household structure and gender differences in travel time: spouse/partner presence, parenthood, and breadwinner status**	To analyze the travel time of metropolitan workers stratified by household structure.	U.S.	American Time Use Survey		Log regression, zero-inflated beta regression		
Zhao, Jinbao Wang, Jian Deng, Wei	2015	**Exploring bikesharing travel time and trip chain by gender and day of the week**	To explore bikesharing travel time and trip chain patterns by gender and day of the week.	Nanjing, China	Smart Travel Card	Chi-square, z-scores			
Sweet, Matthias Kanaroglou, Pavlos	2016	**Gender differences: The role of travel and time use in subjective well-being**	To identify links between daily travel times, time use, and subjective well-being (SWB).	Canada	Canadian General Social Survey				Structured equations
Chakrabarti, SandipJoh, Kenneth	2019	**The effect of parenthood on travel behaviour: Evidence from the California Household Travel Survey**	To compare weekday travel behaviour of adult men and women belonging to dual-earner couple households without children, with their adult counterparts in households with one or more young children.	California, U.S.	California Household Travel Survey		OLS	Binary	
Mandhani, Jyoti Nayak, Jogendra K Parida, Manoranjan	2021	**Investigating the Travel Mode Choice of Female Students: Evidence from Dehradun, India**	To analyze the factors influencing travel behaviour of female students commuting by public transport in Dehradun, India.	Dehradun, India	Survey of students			Multivariate	

Table 2.1: Summary of selected quantitative studies on gender and transport. (continued)

Author	Year	Title	Objective	Place	Dataset	Methods			
						Exploratory and Bivariate Data Analysis	*Multivariate methods: Linear Models*	*Multivariate methods: Logit Models*	*Other Methods*
Gao, Jie Yamamoto, Toshiyuki Helbich, Marco	2022	**The role of residential consonance and dissonance between couples in travel behaviour**	To investigate the extent to which residential consonance/dissonance between couples affected travel behaviour at the household level.	Netherlands	Netherlands Mobility Panel Online Survey				PCA
Tilley, Sara Houston, Donald	2016	**The gender turnaround: Young women now traveling more than young men**	To examine how mobility trends are differentiated by gender and birth cohort.	United Kingdom	National Travel Survey		OLS		
Wei-Shiuen Ng Ashley Acker	2018	**Understanding Urban Travel Behaviour by Gender for Efficient and Equitable Transport Policies**	To examine travel behaviour by gender in eight different cities, across three different continents, focusing on transport mode, trip purpose, travel distance and departure time.	Australia; Ireland; Vietnam; Finland; Indonesia; Malaysia; Portugal; Philippines	Local Administrations Travel Survey			Multivariate	
Havet, NathalieBayart, CarolineBonnel, Patrick	2021	**Why do Gender Differences in Daily Mobility Behaviours persistamong workers?**	To analyze how the main determinants of daily mobility affect male and female workers differently.	Rhone-Alpes, France	Regional Travel Survey		Negative binomial, Bivariate-Tobit, Zero-inflated		

2.5.2 Qualitative Methods

Qualitative methods, including focus groups, interviews, and participant-observer techniques can help fill the gaps left by quantitative techniques, as they focus more on experiences and perceptions, allowing for addressing the 'why' of travel behaviours as well as their impacts. Generally, gender mobility studies rely on qualitative methods to capture the lived experiences of women, often in small-scale studies (Haynes et al., 2019).

While qualitative methods fall outside the scope of this thesis, it is important to acknowledge their importance for gender and transport studies. A few examples are presented here. In Adelaide, Australia, in-depth interviews, diary entries (audio/visual/written), and helmet/bicycle mounted video cameras were used to gain insight on the circumstances in which women start and stop cycling throughout their life, and the spatial contexts in which this occurs, by capturing different aspects of the participants' experiences with cycling (Bonham & Wilson, 2012). Similarly, to identify the influential factors on women's intention to use shared taxis, semi-structured and in-depth individual interviews were conducted with 15 women in Tehran, Iran (Firoozi Yeganeh et al., 2022). For a mobility justice study including the gender dimension in Bogotá, Colombia, 'microstories' were collected as short semi-structured interviews of everyday personal travel experiences to understand what enables or hinders individual mobility from a capabilities approach, and later were analyzed by reconstructing them through texts and cartographies (Vecchio, 2020). In London, interviews were used to explore how and why the meanings of cycling might resonate differently across urban, gendered, ethnic, and class identities, by processing them with detailed open coding of data, later developing conceptual coding schemes and an iterative approach to generate core concepts around cycling (Steinbach et al., 2011). These examples illustrate how qualitative methods help uncover the lived experiences of women and underlying social structures shaping gendered mobilities, factors that can be obscured by large-scale surveys.

2.5.3 Mixed Methods

In gender and transport research, an increasing number of studies employ mixed methods. Mixed approaches allow for identifying patterns from data and gaining additional insights from the qualitative approach atop the quantitative approach, or vice-versa. For example, Shirgaokar and

Lanyi-Bennett (2020) performed a study in two phases: first, conducting focus groups with non-probabilistic sampling to explore how professional women and men think about daily time use in relation to transport choices; in the second phase, fitting weighted robust regression models to examine gender differences in daily time spent driving or riding as a passenger by car using Canada's 2015 General Social Survey. The authors reported that the mixed methods approach helped with understanding the deeper connections between time constraints and travel behaviour, though not all findings from the focus groups were clearly supported in the statistical analysis. In another example in Concepción, Chile, Jirón et al. (2020) applied a survey of 120 individuals from low-, medium-, and high-income groups. Then, a subsample of 20 individuals was selected for ethnographic observation. The ethnographic shadowing technique was applied by five anthropologists, three women and two men, who accompanied participants on their daily routines. The ethnographers took notes and recorded images (through filming or taking pictures), sharing and collaboratively reflecting on their experience on the move. The resulting ethnographic material was used as data to be analyzed collectively and comparatively among researchers, to understand both mobility experiences as well as the significance of the journeys, and was enriched by data from the survey. The authors highlighted how the ethnographic approach allowed them to identify understudied aspects of travel, such as mobility of care patterns, and to go beyond the habitually dichotomous classifications of private and public space, productive and reproductive roles, individual versus interdependent decision-making, and other complex arrangements that go beyond the simplified perspective of daily travel portrayed mostly by commuters to work.

While this thesis focuses on quantitative methodologies, it is important to acknowledge that such approaches can only partially contribute to the development of more equitable transport systems. Qualitative and mixed methods complement quantitative analyses by enabling a deeper understanding of mobility strategies and practices, as they provide richer and more detailed descriptions of everyday travel experiences (Jiron & Carrasco, 2019). These approaches capture lived experiences, perceptions, and social dynamics that are often not observable in large-scale datasets. By offering contextualized insights into how individuals experience and navigate transport systems, they help interpret quantitative findings and support a more comprehensive understanding of gendered mobility patterns.

2.5.4 Geospatial Analysis

While transportation studies usually consider the inherent spatial component of mobility, through geolocated data, more advanced spatial analysis on the gendered patterns of travel are rarely performed. An increasing number and complexity of spatial methods are available and used by gender and transport researchers. They mainly build on techniques from spatial analysis and Geographic Information Systems (GIS), such as accessibility modelling, spatial clustering, and spatial regression, which make it possible to examine how gendered mobility patterns vary across space.

One stream of research seeks to develop methods to visualize and quantify in space the mobility patterns of men and women. In early work on this topic, Kwan (1999a) implemented space-time accessibility with a network-based GIS method based on the space-time prism construct to analyze the spatial patterns of different individuals, men and women. Three space-time accessibility measures were computed for each individual in the subsample, based on travel diaries. The paper presents the concept of the daily potential path area (DPPA), which is the aggregated set of all feasible opportunities between pairs of locations of fixed activities for the day. Results of the analysis indicated that women have lower levels of individual access to urban opportunities when compared to men. More recently, Soukhov et al. (2025) perform a gender-aware accessibility analysis of mobility of care destinations. They use a cumulative-opportunities measure and a competitive and a singly-constrained accessibility measure (spatial availability) with two travel time thresholds (trips shorter than 15 minutes and 30 minutes) in Hamilton, Canada. Results indicate that accessibility by car is exceptionally high across the city, while access by public transport, cycling, and on foot is relatively low, with some exceptions in the inner city. However, the method does not distinguish differences in patterns between men and women.

In a study in Santiago, Chile, urban mobility patterns were analyzed from a gender perspective using three months of phone records of anonymized mobile phone users, census data, GTFS (General Transit Feed Specification) data, and Points of Interest (POI) data (Gauvin et al., 2020). The study measured the excess ratio of visits (women to men) in areas characterized by different categories of POI by computing a multivariate Kernel Density Estimation of POI density, and then assessing the significance of the POI category using spatial sampling and spatial perturbation. The analysis revealed a gender gap in mobility: women visit fewer unique locations than men, and by

mapping this mobility gap over administrative divisions, it found a wider gap associated with lower income and lack of public and private transportation options. Qualitative approaches have also been put forward to shed light on the spatial patterns. A study in India presented the result of collective mapping experiences in Mumbai to represent the everyday production of gendered urban space, representing public spaces in drawings by observation and other exercises based on a participatory methodology made for two pedagogic activities. Results showed similarity in responses to the mapping exercises across age and class, suggesting a shared way of thinking about gendered space (Ranade, 2007). To put women's voices at the centre, Gollaz Moran (2022) applied trajectory mapping by talking to women about their daily routines and asking about their trajectories: origin and destination points, time spent by mode, and the type of trajectory; gendered and embodied feelings (emotions and constraints faced in the different points of their trip related to gendered dynamics, infrastructure, and violence); and, strategies they use for navigating space (personal and/or collective). Then, relief maps were created as a systematic tool to understand how subjectivity is constructed.

Overall, spatial analyses enable the identification of geographically uneven mobility opportunities and constraints between men and women, revealing how the interaction between land use patterns, transport infrastructure, and social characteristics contributes to gendered inequalities in access and travel behaviours. While the spatial aspect of travel is always implicit in transportation and mobility research, methods that explicitly incorporate this aspect in their analysis may be useful in revealing geographical nuance in gendered mobility.

2.6 Literature Synthesis and Research Gaps

This overview of the literature showed that there is a perceivable, quantifiable, and persistent difference in how men and women plan and experience their daily journeys through the city. It has been shown that gender differences are starker in lower socio-economic sections of society, and that some of the main factors that differentiate travel by gender are the presence of young children in the household, race/ethnicity, and the perception of safety during the journey. All of these factors interact in ways that vary depending on the specific social and geographical context where the research has been made. The overview also hints at a trend in research methods, which are increasingly shifting to mixed methods approaches and incorporating spatial analysis to complement gaps traditionally left by quantitative research performed alone.

2.6.1 General Gaps

The literature consistently highlights several key research gaps. First, there is a need to better understand how specific contextual factors shape the interplay between gender and mobility. Second, there is a clear demand for the development of methodologies that enable the collection and analysis of gender-sensitive data. More broadly, gender-centred geospatial analyses remain limited, and parts of the existing literature are now dated. Additionally, the literature emphasizes the importance of examining the diverse needs of different groups of women, moving beyond homogeneous representations of gender. Lastly, the majority of studies focus on travel patterns related to commuting, particularly journeys to and from work. However, as highlighted by numerous authors, other types of trips – such as those related to care and leisure – are comparatively understudied, despite potentially representing a substantial share of overall travel. This gap suggests an important opportunity to examine a wider range of trip purposes, their characteristics, and the transport needs they entail. Notably, these research gaps are systemic and cut across multiple dimensions of transport research, including travel behaviour, accessibility, and transport disadvantage.

These gaps have significant implications in terms of equitable transport planning, as limited empirical evidence on gendered mobility patterns can lead to policies and infrastructures that inadequately reflect the diverse needs of urban populations. Addressing these gaps would support the development of transport systems that better account for gender differences in daily activity

patterns, caregiving responsibilities, and spatial access to opportunities, thereby contributing to more inclusive and responsive planning practices.

2.6.2 Contextual Gaps

Significant gaps are also evident at the regional level. In North America, there is limited research examining differences in attitudes and behaviours between men and women, particularly in relation to emerging concepts such as travel dissonance, which has been more extensively studied in Asian contexts. Similarly, there is a notable absence of gender-specific analyses of transport poverty in North America. Furthermore, some geographies, such as rural areas and variations across urban scales, remain understudied.

In Canada, Babbar et al. (2022) also highlight the lack of recent detailed studies conducted within the country focused on transport through the gender lens. Some progress has been made in specific areas: recent work has explored gendered cycling patterns in Montréal and Toronto (Giacomantonio et al., 2024; Lam et al., 2024; Ravensbergen, Buliung, & Laliberté, 2020; Ravensbergen, Buliung, & Sersli, 2020; Ravensbergen et al., 2019), and mobility of care has been examined in the Montréal context (Ravensbergen et al., 2022). Research on gender, attitudes, and mode use includes a study on gendered influences on LRT ridership in Montréal (Villafuerte-Diaz et al., 2023), while Preston et al. (2022) provide a broader national analysis of commuting modes among immigrant workers.

Despite these contributions, notable gaps remain: no recent studies were found that examine general travel behaviour through a gender lens, nor spatially detailed analyses of gendered mobility patterns. Similarly, no studies address gender and transport disadvantage directly. Two recent studies address attitudes towards the bicycle and light rail from the gender lens, but not towards other transport modes. These gaps highlight a clear opportunity for further gender-specific transport research in the Canadian context.

In response to these gaps, this thesis is structured around four complementary articles. **Table 2.2** contains a summary of gaps and articles. Article 1 addresses gender differences across varying urban scales by analyzing transport poverty at the national level in Canada, complemented by detailed spatial analyses of cities of different sizes and socio-cultural contexts. Article 2 examines the influence of gender on transport in the local context of Montréal, focusing on differences in distance travelled while controlling for socio-economic factors, geography, and trip purpose. It

also analyzes destination patterns across a range of trip purposes, not limited to commuting, thereby addressing the gap related to non-work travel. Article 3 develops a spatially informed methodology to examine travel flows from a gender perspective, conceptualizing origin-destination relationships as functional connections within the urban system. Together, these articles advance geospatial analyses of gendered transport patterns from multiple perspectives. Finally, Article 4 explores gender differences in travel dissonance, linking them to socio-economic characteristics. In doing so, it contributes to the gap of exploring differences in attitudes and behaviours between men and women, especially in the North American context. All articles address the differences between different groups of women by looking at the interaction with socio-economic characteristics, family types, etc. Collectively, these four articles address the identified research gaps through a comprehensive and multidimensional analysis of transport shaped by gender. Rather than addressing a single gap through an in-depth examination in each paper, this thesis highlights the interconnected nature of gender across multiple transport processes, demonstrating that gender operates as a cross-cutting dimension influencing diverse aspects of mobility. Further, these four articles explore patterns at national scale (Article 1), then phenomena at local

Table 2.2: Thesis articles and research gaps.

Gaps/Articles	**Article 1**	**Article 2**	**Article 3**	**Article 4**
Gender-disaggregated, spatially-aware analyses across multiple scales and contexts				
Gendered mobility patterns beyond commuting				
Gender-focused studies on differences in travel attitudes and behaviours				
Differences in transport patterns between groups of women				

CHAPTER 3: METHODOLOGY

This thesis employs gender as a central analytical lens, as deployed by Sanchez de Madriaga (2013) and Law (1999), to reveal systematic differences in mobility patterns between men and women and to develop robust gender-aware methods that can meaningfully inform transport planning. It seeks to address the following research gaps: the lack of gender-disaggregated, spatially-aware analyses across multiple scales; the limited understanding of gendered mobility patterns beyond commuting; and contemporary research on gender differences in travel attitudes and behaviours, particularly in Canada.

This section begins by outlining the overall structure of the thesis and then discussing the research articles in section 3.1. Section 3.2 describes the datasets used, followed by the main modelling approaches (section 3.3). Section 3.4 details the software used for analysis. Detailed methodologies are presented within each following chapter that corresponds to each article that constitutes the thesis.

3.1 General Methodology and Research Articles

Figure 3.1 shows the overall methodological approach designed to develop gender-aware analyses in line with the three research questions. This thesis is designed to examine multiple phenomena derived from the combination of transport conditions (and land uses in the city), and personal characteristics, like income, age, ethnicity, attitudes towards transport, and gender. Specifically, through four research articles (RA), the thesis will explore gender differences in transport poverty (RA1), travel behaviour (RA2 and RA3), and travel dissonance (RA4). The identification of these three topics was guided by the research gaps, discussions with Canadian researchers and planners, as well as data availability. While many additional topics merit further investigation, these interrelated themes enable the development of methodologies that capture distinct yet complementary dimensions of gendered mobility.

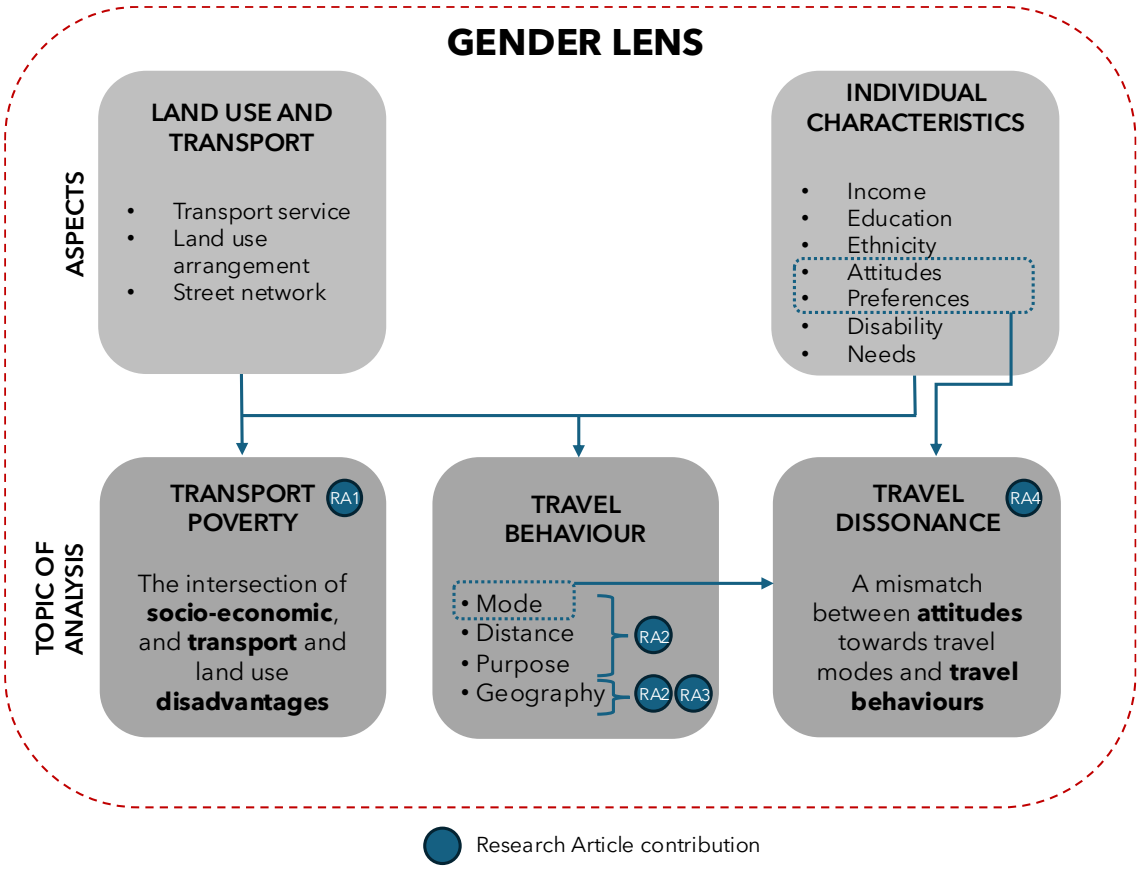

Figure 3.1 Methodological approach and research articles (RA).

3.1.1 Articles

Figure 3.2 presents the main datasets and methods used for each article, alongside their topic of analysis. Article 1 explores statistical and spatial differences in transport poverty between men and women across Canada. Building on a methodology developed for measuring transport poverty across Canada using national datasets, it first employs paired t-tests weighted by population, to assess whether transport poverty, marginalization, and inaccessibility are significantly different between genders. Then, it uses local indicators of spatial autocorrelation (LISA) in selected cities to explore where these differences take place and if the spatial patterns differ by gender. Taken together, these two analyses contribute to answering RQ1 (differences in transport patterns between men and women) and RQ2 (interactions between land use, personal characteristics, and transport). The study was presented at the Transportation Research Board (TRB) International Conference on Women and Gender in Transportation in September 2024, and later published in

Findings in 2025. This article is supported by an article included in Appendix A, that focused on developing the index for measuring transport poverty. As it is not a gender analysis itself, it was included as an appendix in the thesis. It was submitted to *Sustainable Transport and Livability* in December 2025. A pre-print was included in the CIRRELT repository in May 2025. An earlier version was presented at the American Association of Geographers conference in March 2023. The development of this index is a part of the Mobilizing Justice pan-Canadian research project.

Article 2 examines the differences in travel behaviour between men and women in Montréal, Canada. It focuses first on distance, with descriptive statistics and a linear regression to explore the socio-economic determinants of distance, by gender. Then, it makes a spatial exploration of the destinations that men and women travel to for different travel purposes with local indicators of spatial autocorrelation (LISA). Again, these two analyses contribute to answering RQ1 and RQ2, by exploring gender differences in travel behavior as well as the interactions between land uses (destinations) and individual characteristics (gender). The results of this article were presented at the TRB Annual Meeting in 2023, receiving the Best Paper award by the TRB Standing Committee on Women and Gender in Transportation (AME20). It was later published in the *Journal of Transport Geography* in 2024.

Article 3 analyzes gender differences in spatial patterns of origin-destination flows. First, it uses a spatially-aware method of community detection, Hierarchical Link Clustering (HLC), to classify flows based on their connections, length, and geographical location. Then it categorizes the communities (group of flows) into movement types based on the geometric and angular properties of the flows within the communities. The link classification and movement type classification per gender contributes to answer RQ1, revealing differentiated spatial patterns between men and women. Finally, it uses logistic regression to explore the individual, land use, and transport factors that explain the categorization and determine gender differences in both spatial patterns and explanatory variables, thereby contributing to answering RQ2. Results were presented at the Canadian Transportation Research Forum (CTRF) 2025, and the article was submitted for publication to *Applied Geography* later that year.

Article 4 explores gender differences in travel mode dissonance, the mismatch between the desired travel mode and the one used. Factor analysis was used to create constructs of attitudes towards travel modes, and gender similarities and differences in these constructs were explored. This

analysis contributes to RQ1 by reflecting on the differences in patterns between men and women. This article is the only one without explicit spatial analysis, therefore, partially answers to RQ1. Then, multinomial logistic regression was used to identify the factors explaining the dissonance types, and how these factors may vary by gender. Similar to the other articles, the regression contributes to answering RQ2, by exploring the interactions between land use, transport, and individual characteristics. This article will be presented at the World Conference on Transport Research Society (WCTR) 2026 and was submitted for publication to *Travel Behaviour and Society*.

Lastly, taken together, the four articles develop innovative methodologies applied to gender and transport using a variety of existing datasets. In doing so, it helps in answering RQ3, on how to leverage use existing transport data to reveal gendered patterns in transport. **Figure 3.3** summarizes the research gaps found during the literature review, and which article (or articles) address them, demonstrating a multidimensional and multi-perspective approach to gender issues in transport.

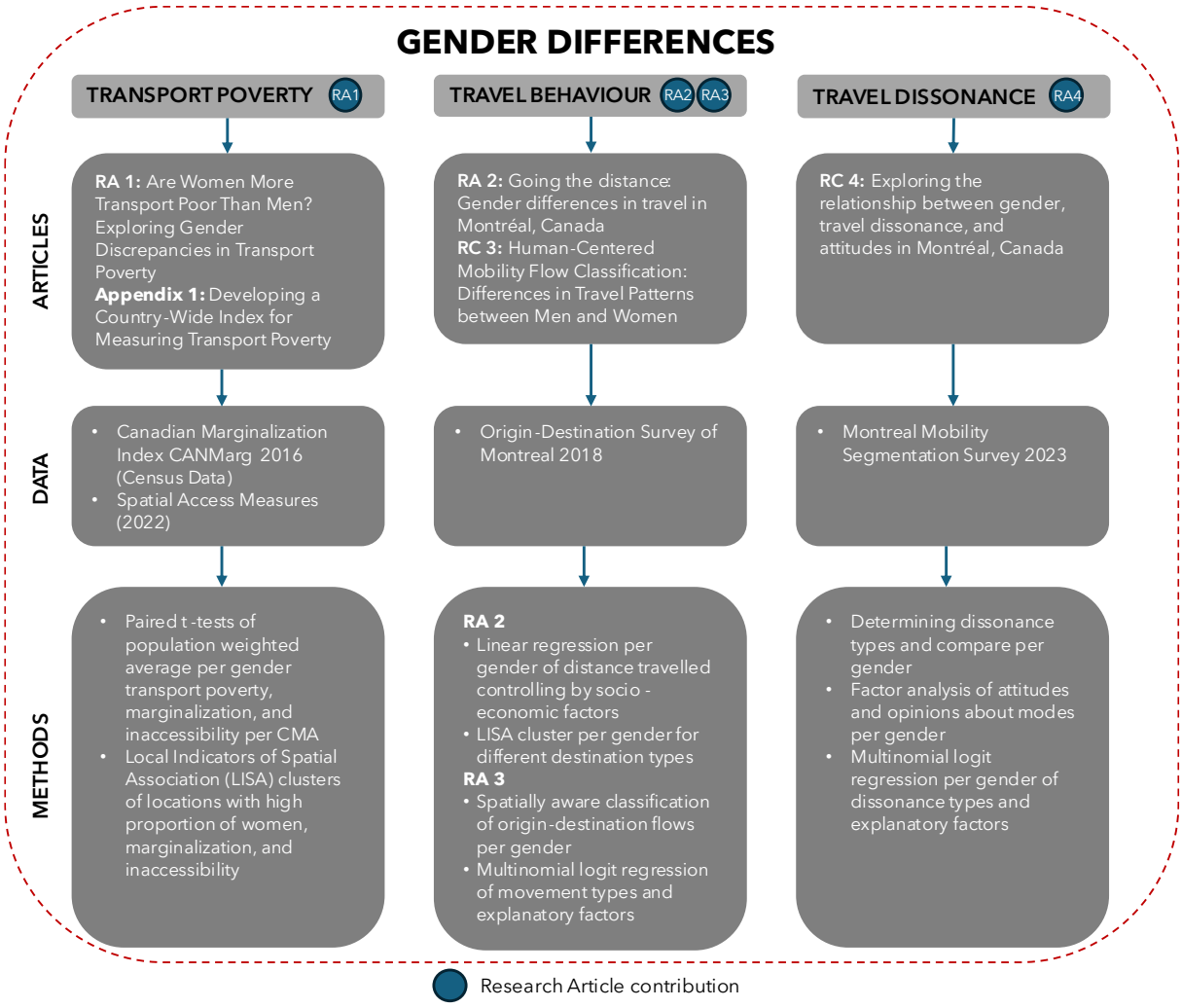

Figure 3.2 Data and processing scheme. Summary of the research articles (RA), data, and methods.

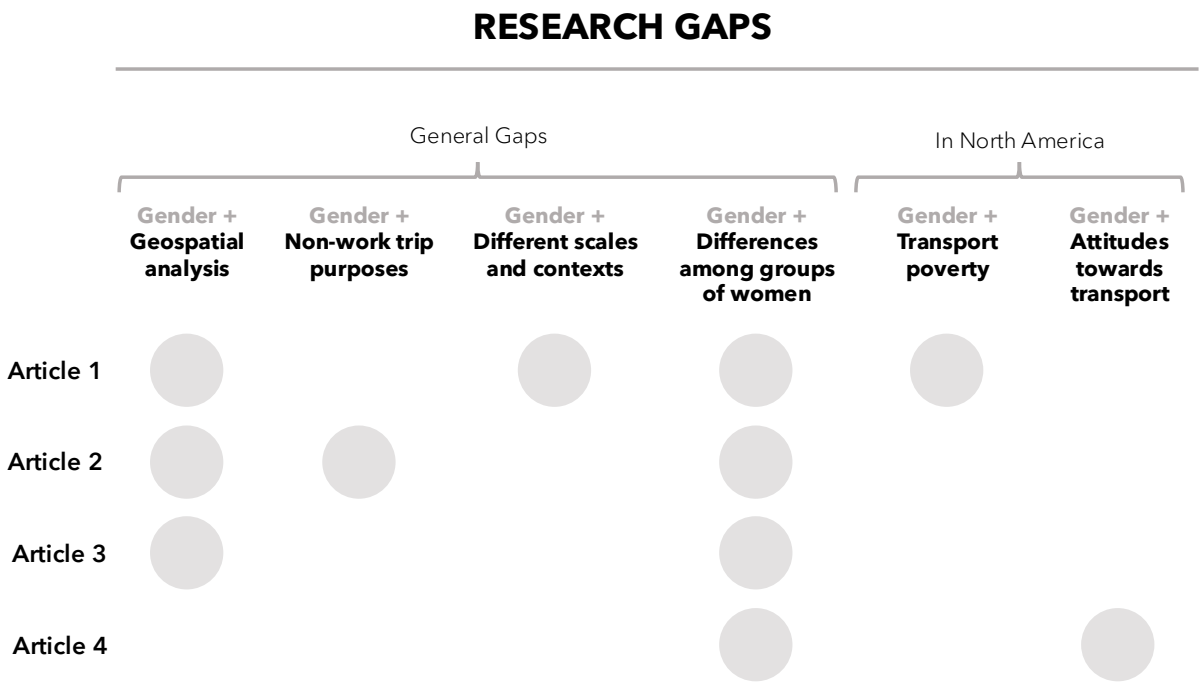

Figure 3.3 Research gaps and articles.

3.2 Data

As presented in **Figure 3.2**, four main secondary data sources, collected by public institutions, are used. These data are standard for transport planning and research, and because they are public, follow a relatively comparable structure to similar data from other geographies. They are also periodically updated. Accordingly, using these sources enhances research reproducibility, comparability, and the capacity for future monitoring.

3.2.1 Main data sources

A detailed account of the variables and datasets used for each article can be found in Appendix B. In this section, we present a broad overview of each dataset to provide the reader with a comprehensive understanding of the data ecosystem of this thesis. More details are presented in the respective articles associated with each dataset.

CanMARG index

The Canadian Marginalization Index (CAN-Marg) (Matheson et al., 2012) is a composite area-based index developed to study multidimensional inequalities between population groups using census data. It was created in 2006, but the 2016 version was used for this thesis, obtained in 2022.

The index is composed of four dimensions. **Households and dwellings** includes indicators that measure the proportion of people living alone, the percentage of population above 15, the average number of people per dwelling, the proportion of dwellings that are apartments in buildings of five or more stories, the proportion of population that are single/divorce/widowed, the percentage of dwellings not owned by their residents, and the proportion of population who moved in the last five years. **Material resources** contains the indicators of proportion of population above 15 years of age without a high-school diploma, the proportion of the population who are single parents, the proportion of total income from government transfer payments for population aged 15+, the proportion of the population aged 15+ who are unemployed, and the average after-tax income for population aged 15+. **Age and labour force** gathers the indicators of proportion of the population ages 65+, the dependency ratio (total population 0-14 and 65+/total population 15-64), and the proportion of the population not participating in labour force (aged 15). Finally, **immigration and visible minority**, with the indicators of percentage of recent immigrants and the percentage who self-identify as a 'visible minority' (defined by Statistics Canada).

The dataset is publicly available and provides a continuous index for all of Canada that combines these four dimensions, and the disaggregated value of each dimension ordered by quintiles for all geographic units in the country. All values are provided at the dissemination area (DA) level and the census tract (CT) level.

This data is used for the first article of this thesis. Specifically, the quintile values of each dimension are used to generate the marginalization index.

Spatial Access Measures

The Spatial Access Measures (Government of Canada, 2023) is a set of indicators that measure accessibility to different categories of amenities by different transport modes for the whole of Canada at the dissemination block (DB) level. It was developed by Statistics Canada initially in 2022, it is publicly available, and the version used for this thesis was from 2023.

These measures are calculated using gravity models for the following categories of facilities: primary and secondary education, postsecondary education, health care, employment, grocery stores, culture, and recreation. For each of these categories, accessibility was calculated by public transport at peak and off-peak hours, by cycling, and on foot.

This dataset is used in the first research article to generate the inaccessibility index.

Origin-Destination Survey

The Origin-Destination Survey of Montréal 2018 is provided by the Regional Authority of Metropolitan Transport (ARTM), the body in charge of orientating mobility policies for the metropolitan region of Montréal, which includes the cities of Laval, Longueuil, and the surrounding suburban and rural areas. A more restricted version of the dataset was open access, and a full version, including locations and economic variables, was available by request for research purposes, and was provided by the ARTM in the winter of 2022. It consists of a travel diary of around 350,000 observations of all trips made by all household members of households within the sample on a regular weekday during the fall. This dataset is collected every five years, and this iteration surveyed a sample of 73,421 households.

The dataset contains several sections: **Household**, with information such as the number of members, number of vehicles, income categories, location anonymized to a grid of 250 m, the ID code of the home census tract (2016), and the municipal sectors of the survey. **Person**, with age, sex, possession of public transport card and drivers license, etc. **Trips**, with details about travel mode, time of day, purpose of the trip, and coordinates of locations of origins and destinations, anonymized to a grid of 250 m. Trip purposes are work, school, shopping, leisure, visits (to friends or relatives), health, accompanying trips (picking up or dropping off someone), return home, other, and indeterminate.

This dataset is used for both RA2 and RA3. It enables the calculation of trip distance and geolocation of origins and destinations (RA2) as well as the generation of origin-destination for RA3.

Montréal Mobility Segmentation Survey

The Montréal Mobility Segmentation Survey was collected by the Regional Authority of Metropolitan Transport (ARTM) with the aim of better understanding travel and attitudes in the

region. It was collected between October and November of 2023 and has a total of 4,057 observations. Although it is not publicly available, access was provided by request in the spring of 2025.

The survey is structured in six different sections: **Socio demographic profile**, with information about occupation, sex, family situation, age, immigration status, education level, income bracket, region of the household, postal code (although, this was not shared, instead, only the region within eight large regions defined for Montréal), etc. **Vehicle ownership and proximity to transport**, with information about possession of cars, motorcycles, and micromobility devices, access and proximity to bus stops, Bixi (bikeshare system) stations, parking, etc. **Transport behaviour**, with information about the frequency of use of different modes, what is their main transport mode and their desired mode, etc. **Importance and satisfaction with transport modes**, including criteria used for choosing a mode. **Perception of transport modes**, with 34 adjectives available and eight modes that the adjectives can be associated with. Finally, **Attitudes**, containing affirmations about the environment, image, values, and technology. Almost all this information was collected as categorical values.

Access to this dataset was instrumental in designing RA4. The attitudinal and transport behaviour variables are used to examine travel dissonance from a gender perspective.

3.2.2 Secondary data sources

Table 3.1 displays a list of secondary data sources that were used for analysis and map styling in the four articles. These datasets mainly comprise census or municipal boundaries of different sizes, land use data, and transport network data.

Table 3.1: Secondary data sources and how they were used.

Name	Article	Source	Year	Use
Census Metropolitan Areas	Article 1	Statistics Canada	2016 and 2021 iterations	Boundaries (Census Geography)
Census Agglomeration	Article 1	Statistics Canada	2016 and 2021 iterations	Boundaries (Census Geography)
Census Tracts	Article 1 Article 2 Article 3	Statistics Canada	2016 and 2021 iterations	Boundaries (Census Geography)
Dissemination Areas	Article 1	Statistics Canada	2016 and 2021 iterations	Boundaries (Census Geography)
Dissemination Blocks	Article 1	Statistics Canada	2016 and 2021 iterations	Boundaries (Census Geography)
Montréal Eight Regions[1]	Article 3 Article 2	ARTM	2018	Boundaries (Municipal Geography, Montréal)
Enhanced Points of Interest (POIs)	Article 2	DMTI Spatial Inc	2021	Land uses
Open Database of Educational Facilities (ODEF)	Article 2	Statistics Canada	2022	Education facilities (Montréal)
Train Network	Article 3	Ministère des Transports et de la Mobilité durable	2025	Rail network (Montréal)
Metro and bus Traces (lines and stops)	Article 2	Société de Transport de Montréal (STM)	2021	Metro network (Montréal)

[1] These regions are used by ARTM and their limits are provided in their datasets. Their names are Downtown, Centre, East, West (within the island), Laval, Longueuil, Couronne Nord and Couronne Sud.

3.3 Main Modelling Approaches

This section presents an overview of the general modelling approaches and how they were used on each article (see **Figure 3.2**) to reveal gendered patterns. Statistical approaches are explained in section 3.3.1 and 3.3.2. Spatial analyses are explained in section 3.3.3.

The main statistical modelling approach that emerged from this work was to fit separate models for men and women. All models were first estimated as a pooled model, with gender as a control variable. Then, distinct models were fitted to understand how the determinants of the dependant variable under investigation vary across genders. It is worth noting that models with gender as interaction terms (for all variables or selected variables) were also tested, but this approach made the interpretation far more complex, as it increased the number of alternatives, a difficulty observed especially with categorical variables with more than three categories. Therefore, for simplicity and clarity of interpretation, it was decided to separate the models by gender. The same approach was undertaken for the descriptive and spatial analyses.

One important limitation of this segmentation approach is that it reduces the sample size available for the analyses. This limitation is more evident when the number of observations in the model is lower, such as when smaller spatial units are used. For example, in Article 3, with 152 observations for women and 175 observations for men. Conversely, when large sample sizes are available, the segmentation process does not substantially limit the analyses. In Article 2, therefore, this is not a consideration given the large sample size (more than 75,000 observations in total for both genders). Limitations will be discussed in detail in Chapters 8 and 9.

3.3.1 Multiple Linear Regression

Linear regressions are typically used in travel behaviour modelling when the dependent variable is continuous. Multiple Linear Regression (MLR) is a model that establishes the relationship between a continuous dependent variable and a set of independent variables. It is an extension of Simple Linear Regression, where variations in the dependent variable (y) can be explained by only one independent variable (x); instead, MLR allows this variation to be explained by multiple independent variables. Linear regression assumes that there is a linear relationship between outcome and explanatory variables, observations are independent, there is a constant variance of errors, a normal distribution of residuals, and there is no collinearity between explanatory factors. MLR corresponds to **Equation 3.1**:

Equation 3.1:

$$Yi = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_{\mathrm{p}} X_{i\mathrm{p}} + \varepsilon$$

Where Yi is an outcome observation, β_0 is the origin coordinate, β_1, β_2 ... are coefficients, X_{i1}, X_{i2} ... are the i observation of explanatory variables, and ε represents residual errors.

Bootstrapping is a complementary method used to estimate the uncertainty (standard errors, confidence intervals) of regression coefficients by repeatedly resampling data (Efron, 1979; Horowitz, 2019). The resampling is repeated a large number of times (in this case 1,000), and with each resampling, estimates are computed. This process allows for deriving estimates of standard errors and confidence intervals that describe the population, and can be applicable to regressions. Bootstrapping a regression model helps understanding how variable the model parameters are, and has been used in transportation research for other applications, especially for large datasets (Naik et al., 2018; Yen et al., 2023).

This modelling approach, based on MLR with bootstrapping, was applied in Article 2 to examine gender differences in the mean distance travelled. Given that the dependent variable is continuous, this regression is appropriate. However, due to the large sample size, preliminary results indicated that all explanatory variables were statistically significant. To address this issue and better identify meaningful differences between men and women, a bootstrapping resampling procedure was implemented to generate more robust confidence intervals for the estimated parameters.

Linear regressions were initially tested, and finally a log-linear regression was chosen, given that the distribution of the dependent variable for Article 2 was right-skewed (with more observations in the lower value ranges). The variable represents distance travelled, implying many short trips, and a few very long ones. This operation was effective at converting the skewness and normalizing the distribution of the data. The independent variables included in the model generation were chosen based on a combination of a literature review about the topic and data availability. The final variables of the model were then selected with a combination of tests of collinearity with other variables, the effect of a particular variable on the R-squared values of the model and the likelihood-ratio test of the models with and without a given variable. A more detailed description of included and excluded variables can be found in the *Methodology* section of *Chapter 5, Article 2*.

From the bootstrapping process, the women's model has an $R^2 \approx 0.15$ with a highly stable confidence interval across subsamples (90% CI: 0.147–0.159). The men's model has an $R^2 \approx 0.19$. Bootstrap resampling (1,000 iterations) shows that this estimate is also highly stable (90% CI: 0.187–0.199); both results are consistent with behavioural transport models where unobserved heterogeneity limits overall explanatory power. The final models presented for men and women had no multicollinearity between the predictors according to the Variance Inflation Factor (VIF) diagnostic (all VIF values <5). Heteroscedasticity and non-normality of residuals were present, but this is not uncommon in large samples (~39,600 trip observations for women and ~36,900 for men in this case), as with large samples, even minor deviations from normality or homoscedasticity may lead formal diagnostic tests to reject null hypotheses due to increased statistical power (Greene, 2012; White & Macdonald, 1980). The bootstrapping process using pairs with 1,000 replications used to generate confidence intervals for the comparison between genders (described earlier in this section) is a robust approach to account for heteroscedasticity and residual non-normality as well. Unlike conventional parametric inference, pairs bootstrapping does not rely on homoscedasticity assumptions and is therefore considered more robust in large observational samples with heterogeneous error structures (Cribari-Neto & Zarkos, 1999; Flachaire, 2005).

3.3.2 Multinomial Logistic Regression

Multinomial Logistic Regression is a model used to predict the probability of belonging to or choosing a category, given a set of independent variables, when the dependent variable is categorical with more than two categories. It is used to analyze individual decision-making behaviour, based, mathematically, on probability theory, and frequently applied in transportation research (DeWeese & El-Geneidy, 2020; Farooq et al., 2025; Moniruzzaman & Páez, 2012). The multinomial logit (MNL) model expresses the probability P that an individual n chooses an alternative i as a function of the systematic utility term V_{ni}, such that:

Equation 3.2:

$$P_{ni} = \frac{\exp(V_{ni})}{\sum_{j \in C_n} \exp\,(V_{nj})}$$

A practical operational equation for this model is used by Croissant (2020), decomposing the utility into three components:

Equation 3.3:

$$V_{ni} = \beta' X_{ni} + \gamma_i' Z_n + \delta_i' W_{ni}$$

Where first term ($\beta' X_{ni}$) includes alternative-specific variables with generic coefficients that are constant across alternatives, the second term ($\gamma_i' Z_n$) captures individual-specific variables whose effects vary by alternatives through alternative-specific coefficients, and the third term ($\delta_i' W_{ni}$) allows alternative-specific variables to also have alternative-specific coefficients, introducing additional flexibility.

This approach is often used in transportation to model modal choice (Anas, 1981; Lo et al., 2004; Shen, 2012). In this thesis it was used for Article 3 and Article 4. In Article 3, movement types were created by grouping origin-destination flows classified by gender. Movement types were designated according to the angular variation of the flows within a group and the shape of the convex hull that wrapped all flows in the group. The multinomial logit was then applied to understand socio-economic factors, urban factors, and transport factors that explain the probability of a given flow to belong to a certain movement type, and how the effect of these explanatory variables vary by gender. In Article 4, modal dissonance categories were created by analyzing the mismatch between preferred and used travel modes. Then, multinomial logit regressions per gender were applied using attitudes towards transport, along with socio-economic factors, to explain variations by gender with respect to travel dissonance categories.

The independent variables included in the estimation of the models were chosen based on a combination of a literature review about the topic and data availability at the spatial scale that was analyzed. The final variables of the model were then selected in a parsimonious step-wise process with a combination of the effect of a particular variable on the McFadden values of the model and a likelihood-ratio test of the model with and without each variable. The interactions between the different variables, although less problematic in logistic modelling, were assessed through the step-wise process. A more detailed description of included and excluded variables can be found in the Methodology section of Chapter 6 (Article 3) and Chapter 7 (Article 4). As for the model performance, the log-likelihood and McFadden R-squared are reported in the Tables in the results section of each chapter. Overall, given the novelty of Articles 3 and 4, the regression was exploratory, and more efforts are warranted to validate and investigate the relation between the outcomes and related variables.

3.3.3 Spatial Analysis

Local Indicators of Spatial Association (LISA)

Like other spatial statistics approaches, Local Indicators of Spatial Association (LISA) are designed to reject a null hypothesis that the values that describe a given phenomenon are randomly distributed across a given area. Instead, the alternative hypothesis is that there exists some level of spatial clustering of values, and that the location of these clusters is statistically significant (Anselin, 1995). This is defined by the **Equation 3.4**:

Equation 3.4:

$$I_i = \frac{\mathrm{x}_i - \bar{x}}{\mathrm{m2}} \sum_j w_{ij} z_j$$

where x_i is the value of the variable at location i, $\bar{x}$ is the mean of the variable across all locations, w_{ij} represents the spatial weight between locations i and j, and m_2 is a normalization factor equal to the variance term:

Equation 3.5:

$$\frac{1}{n} \sum\nolimits_j (x_j - \bar{x})^2$$

and *n* is the number of elements. This formulation links each spatial observation to the values of its neighbours, capturing the degree to which a location is surrounded by similar or dissimilar values. Positive values of I_i indicate local clustering of similar values (high-high or low-low), while negative values indicate spatial outliers (high-low or low-high). This assessment can also be bivariate, so that it captures the relationship between the value for one variable at location *i*, and the average of the neighbouring values for another variable, *yi*, and its spatial lag $\sum_j w_{ij} y_j$. This method is common in urban geographical analysis and transport research (Chacon-Hurtado et al., 2020; B. Zhu et al., 2018).

This approach was used in Articles 1 and 2. Article 1 used the bivariate form, to find spatial variations in transport poverty differentiated by gender, to assess simultaneously the values of marginalization and the proportion of women, and of inaccessibility and the proportion of women. Both inaccessibility and marginalization are components of transport poverty; therefore, an

overlay of both can indicate the occurrence of transport poverty and the areas where transportation interventions could be applied. In Article 2, it was used univariately, to identify gender differences in areas that serve as destinations for different types of trip purposes. In other words, it evaluated if areas where men and women go for different purposes spatially differ, and if these differences are statistically significant.

Spatially-aware Hierarchical Link Clustering (HLC) Classification

Hierarchical Link Clustering (HLC) Classification, proposed by Anh et al. (2010), offers a useful conceptual extension for the analysis of transport and mobility systems. Traditionally, transport networks are represented as graphs in which nodes correspond to spatial units such as zones or stations, and links represent connections such as trips, flows, or infrastructure. Most community detection methods applied to these networks focus on grouping nodes into mutually exclusive clusters, implicitly assuming that each spatial unit belongs to a single functional region. However, this assumption is often restrictive in the context of everyday mobility, where individuals and places are embedded in multiple, overlapping systems of movement. The link community approach addresses this limitation by shifting the focus from nodes to links. Rather than clustering locations, it groups connections (links) based on their similarity, thereby defining communities as sets of flows instead of sets of places. To evaluate similarity, the Tanimoto similarity method is used (Tanimoto, 1958), with the **Equation 3.6**:

Equation 3.6:

$$S(f_{ki}f_{ki}) = \frac{a_i * a_j}{\lceil a_i^2 \rceil + \lceil a_j^2 \rceil - a_i * a_j}$$

Where the similarity is between edges *ki* and *kj*, with *k* being a node in common, and arrays *ai* and *aj* are the weights of the flows associated with the nodes.

For the weight of each flow, Sekulic et al. (2021) insert geographical information in the similarity calculation, adding the distance between two points (the length of the flow, or the real distance of the trip, if available) through an exponential function, and the 'magnitude' of the flow, meaning the number of people traveling represented by a flow. This enables creating a weight in which the length of the trip and the people travelling through it are constitutive characteristics of evaluated

similarity, as opposed to algorithms that only evaluate the system of connections. It tries to capture the functional structure of the network.

This approach was used in Article 3 to classify origin-destination pairs into movement types. Two distinct analyses were conducted for men and women. These analyses enable understanding if women and men have different movement patterns, and/or if movement patterns can be identified in different areas of the city.

3.4 Modelling Software

For most statistical modelling, RStudio (Posit Team, 2025) was used with open-source packages from the Comprehensive R Archive Network (CRAN) repository. For the Article 1, linear regression was done with the *lm* embedded function, and the bootstrapping used the *Boot* and *Confint* functions of the package *car* (Fox & Weisberg, 2019). For the multinomial logit regressions in Articles 3 and 4, the function *mlogit* (Croissant, 2020) of the package with the same name was used. The spatial autocorrelation (LISA) processes used in Articles 1 and 2 were ran in the GeoDa software (Anselin et al., 2006). The HLC clustering analysis in Article 3 was ran on Python version 3.8.19 with the packages *igraph* (Csárdi & Nepusz, 2006), *pandas, os, click, array, operator, numpy, optparse, textwrap, math* and *parse*. All maps were created and styled in QGIS (QGIS.org, 2025).

CHAPTER 4: ARTICLE 1: ARE WOMEN MORE TRANSPORT POOR THAN MEN? EXPLORING GENDER DISCREPANCIES IN TRANSPORT POVERTY

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Findings

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4.1 Questions

Transport poverty (TP) is a multidimensional phenomenon, referring to the systemic inability to reach destinations for a person or group, whether for lack of service, infrastructure, resources, time, available destinations, etc. (Lucas et al., 2016). From a land use and transport perspective, lack of accessibility to destinations and socio-economic marginalization are two key components contributing to the risk of TP.

Women are more likely to experience TP, especially if they are also immigrants, members of ethnic minority communities, or if they experience disabilities (S.-O. Kim et al., 2024), indicating the effect of intersectionality (Crenshaw, 1991), or how gender interacts with other individual characteristics to create unique lived experiences. In this context, we ask:

Are there differences in transport poverty between men and women in Canada?
Within urban areas, are there clustered areas with high levels of transport poverty, inaccessibility, marginalization, and a high proportion of women?

4.2 Methods

To answer the first question, we assigned a transport poverty index to every Dissemination Area (DA), the smallest geographic unit of the Canadian census (400-700 inhabitants). This index draws on previous work (see (2025)) and integrates two components: a marginalization subindex and an

inaccessibility subindex. Marginalization is understood as a multidimensional phenomenon in which persons or groups are deprived from important socio-political experiences (e.g., control over self-will, access to critical resources, mobility) (Hall & Carlson, 2016). Operationally, the marginalization subindex from Matheson et al. (2012) combines four dimensions (household conditions, material resources, age of the population, immigration and visible minorities) with equal weights. The inaccessibility subindex (M. L. G. Guerrero-Balarezo et al., 2025) combines accessibility measures to different urban services weighted by their potential for trip generation using three different modes with equal weights: public transport, bicycle, and on foot. Both subindexes are then combined with a weight of 50% each, to compose a measure of transport poverty (**Equation 4.1**).

Equation 4.1:

$$\text{Transport Poverty (TP)} = \text{Marginalization} * 0.5 + \text{Inaccessibility} * 0.5$$

Then, we averaged these three indexes for each urban area in Canada (Census Metropolitan Area (CMA) and Census Agglomeration (CA) (Statistics Canada, 2021b) by gender, by weighting the average of the values per DA based on the number of women and men. **Equation 4.2** summarizes this process for calculating the average indexes for each urban area, with TP and women as an example, but this was also repeated for men, and for each of the subindexes.

Equation 4.2:

$$TP_{W,A_i} = \frac{\sum_{i=1}^{N} TP_{DA_i} * \text{ Number of Women in } DA_i}{\sum_{i=1}^{N} \text{ Number of Women in } DA_i}$$

Where TP_{W,A_i} corresponds to the average TP index for women in urban area A_i, and N corresponds to the number of DA in the urban area A_i.

Finally, we performed a paired t-test (based on the urban area) of the average TP index to evaluate whether there is a significant difference between the TP averages of men and women.

To answer the second question, we performed Local Indicators of Spatial Association (LISA) analyses (Anselin, 1995) at the DA level, using Montréal and Hamilton as study cases, to understand the relations between the spatial distribution of women, transport poverty, inaccessibility, and marginalization. These cities were chosen to capture different urban sizes and dynamics that may generate different gendered patterns of TP. Montréal is a large urban area

(metropolitan population > 4 million) with a large centralized public transport network, while Hamilton is an intermediate city (population around 750,000), served by a local bus system. Additionally, both cities occupy different positions in their urban city systems: Montréal is the core metropolitan area of its region, while Hamilton is a city under the influence of the large metropolitan area of Toronto. Finally, both cities are representative of different urban-cultural landscapes, as Montréal developed under French influence, while Hamilton developed under English culture. For each urban area, two LISA analyses were conducted: (i) marginalization and proportion of women, and (ii) inaccessibility and proportion of women. This approach follows an intersectional approach, as it combines age, ethnicity (minorities), and economic conditions with gender. Results were then overlayed to identify clusters of TP, with high marginalization, high inaccessibility, and a high proportion of women. For the spatial matrix used in the LISA analyses, we tested distance matrices of the type k-nearest neighbours (knn) with an inverse distance power of two, with different numbers of neighbours. This type of matrix was chosen because the inverted distance from the centroid enables accounting for the effect of the diminishing influence of far elements in polygons of varying sizes, like DAs. Results were consistent for different numbers of neighbours, and we decided on a matrix of 80 knn.

4.3 Findings

The average TP per urban area shows that women have a higher TP index in most urban areas. **Figure 4.1a** shows the paired plot of this measure per gender (with urban areas ordered from the lowest to the highest TP index). The curve of TP for women is, in most cases, to the right of the curve for men. This indicates women have a higher TP index, a finding congruent with Tiznado Aitken et al. (2024), which found that women are more time poor than men in a transport-related time poverty analysis. In **Figure 4.1b**, we can see that women have a lower average inaccessibility (to the left of the curve of men), implying they have more access to destinations than men by public and active transport. Finally, **Figure 4.1c** shows the paired subindex of marginalization, where women have a higher average index of marginalization than do men. Although women have a higher access to destinations, the combination with a higher marginalization index leads to overall higher TP among women.

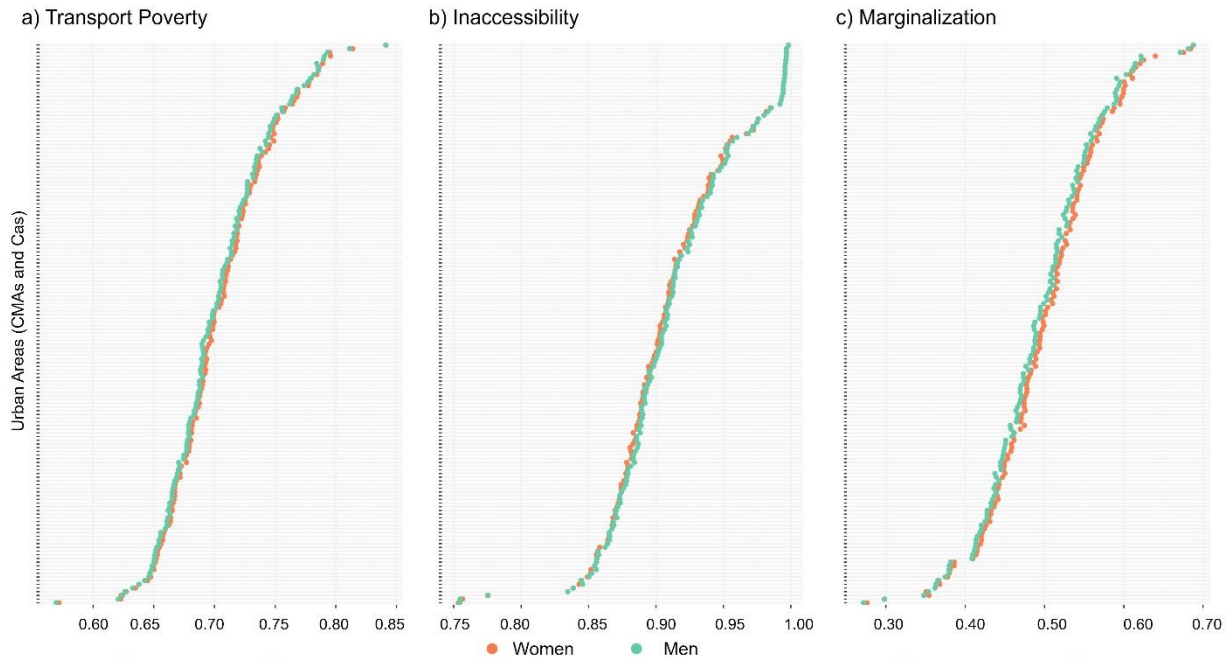

Figure 4.1. Weighted measures of transport poverty, marginalization, and inaccessibility by gender, paired by urban area.

In **Table 4.1**, the result of the paired t-test for these three measures shows that the difference is statistically significant for all tests performed. A sensitivity analysis was conducted with varying weights of the subindexes. We tested the following weights: 25% Marginalization–75% Inaccessibility, and 75% Marginalization–25% Inaccessibility. In both cases, women continue to be more transport poor than men, with a significantly higher average TP index as compared to men.

Table 4.1: Paired t-tests of transport poverty, marginalization, and inaccessibility by gender.

Comparison	Mean Women	Mean Men	Coefficient	p. value
Average Transport Poverty (TP) index	0.705	0.702	0.0023	< 0.001
Inaccessibility subindex	0.910	0.911	-0.0014	<0.001
Marginalization subindex	0.499	0.492	0.006	<0.001

Although the average results seem to imply that women are more transport poor due to the marginalization component, the overlay of the spatial analyses results in **Figure 4.2** discloses a more nuanced picture, by unmasking critical spatial disparities. In squared hatch over red, we identify the significant local clusters of high values of inaccessibility/proportion of women and marginalization/proportion of women. From an intersectional perspective, the areas with a high proportion of women and a high marginalization are more likely to concentrate women characterized by socio-economic factors that, when combined with inaccessibility, result in adverse conditions. These areas where the high values of the three measures converge are surrounded by larger areas (in squared hatch) of inaccessibility and a high proportion of women (without the high marginalization component). In both cities, which are in other respects dissimilar, the same geographical pattern occurs: these areas in need of intervention concentrate in suburban nodes that encircle the downtown core of the two cities. This implies that although in the averaged measures women have more accessibility, the geographical disaggregation shows places where women have a disadvantage in access. The spatial analysis demonstrates the utility of this index for identifying geographical nuances in transport poverty for different population segments in Canadian cities. Combining the three measures through this spatial approach enables identifying areas that could be prioritized for transport interventions to reduce TP among women and, thereby, address the consistent gap observed across all urban areas.

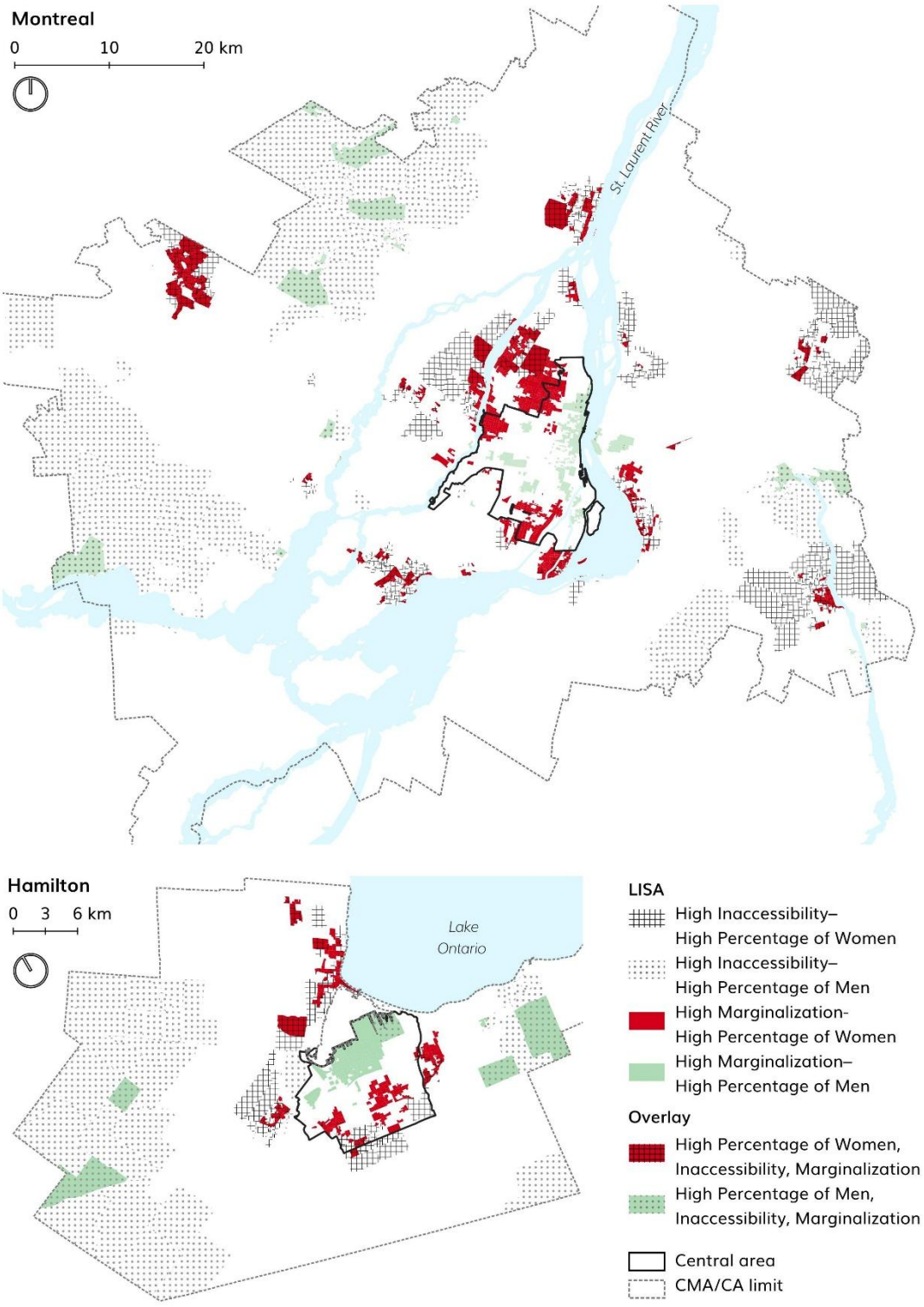

Figure 4.2 Maps of spatial clustering of marginalization, inaccessibility, and high proportion of men/women

CHAPTER 5: ARTICLE 2: GOING THE DISTANCE: GENDER DIFFERENCES IN TRAVEL IN MONTRÉAL, CANADA

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5.1 Introduction

Policy and investment decisions in transport have historically been based on cost-benefit considerations, usually favoring the travel needs of adult working men (Guevara & Alvarez, 2019). Hence, transport systems often neglect women's distinct mobility needs and travel patterns, thereby supporting structural inequalities (Sanchez de Madriaga, 2013). At the same time, there is a lack of gender-oriented evidence to support equitable transport planning (Hanson, 2010). To fill this gap, research has emerged in recent years to specifically examine the travel behaviour of women. Research on the topic tends to focus on mode and purpose, descriptive statistics, and statistical modelling, leaving spatial patterns less explored, which could be key for designing better transport policies.

Hine (2012) highlights that there are clear issues affecting women's transport related to patterns of travel, employment, income, caring responsibilities, and access to transport modes. They also cite a range of reasons why women should be distinctly considered in transport planning, such as the multiple roles they play and their primary responsibility in the household, more constrained opportunities for paid employment, and a much greater likelihood of being engaged in part-time and/or casual employment, which is usually also more local. In fact, since women and men often do not play the same roles in the household, policies that assume that both genders have the same travel patterns and needs may not completely achieve their goals if they do not consider gender explicitly (Ng & Acker, 2018). Further, the current layout of transport systems, can be

unsupportive of women's needs for travel. For example, García-Jiménez et al. (2020) describe some factors that hinder a larger share of women from using bike-sharing systems, including unsafe driving conditions, and a need for more traffic rules and speed limits on public roads, with many claiming they prefer cycling in zones with lower traffic; these are all factors that could be addressed by urban policy or urban design. In this light, it is necessary for researchers to investigate the differential way that women use and engage with transport systems.

The objective of this study is to examine the variations between the spatial travel patterns of men and women in Montréal, Canada, to answer the following questions: (i) how do spatial travel patterns vary between men and women, and (ii) how do travel-influencing factors affect men and women differently? For this purpose, distances travelled (as a first spatial manifestation) and the localization of the destinations are analyzed by gender. Starting with a descriptive analysis and following with a bootstrapped linear regression by gender, the distance travelled and its relationship with socio-economic characteristics are examined. Then, with an exploratory purpose, geolocated destinations are examined to identify spatial patterns with global and local spatial autocorrelation analyses, to test if variations may not only be identified in terms of distance, but also investigating if different groups (genders) differently occupy urban space. By presenting the main differences in travel patterns between women and men, as well as the differences in terms of possible explanatory variables, the study gives insights to guide transport planning policies to address some of the gender gaps from a gender inclusivity lens.

The following section contains the literature review, followed by an explanation of the methodology (variables and processes). The fourth section highlights the descriptive analysis, the modelling results and the spatial analysis. The fifth section contains a discussion of these results, and the sixth, the conclusion, with lessons learned and areas for future research.

5.2 Literature Research

The high density of urban populations and the increasing rates of urbanization and urban growth make urban transport a critical system, which provides access to essential activities and enables citizens to "appropriate" their right to the city and to perform urban citizenship (Levy, 2013). Gender and mobility are inseparable, influencing each other in profound and often subtle ways (Hanson, 2010). This dynamic is intrinsically linked to the social construction of urban space.

Masculinity and femininity are molded onto individuals through social interactions and expectations, for instance, risk perception varies between men and women, producing a difference in the limits, the reach and the desire to inhabit and occupy urban space (Yuan et al., 2023). Other factors influenced by gender for producing urban space include the right to inhabit the urban realm, the negotiation of who caters for household needs, etc. How far we want to go into urban space, and by which means are directly related to transport. Despite these intricacies, mainstream transport planning still remains largely untouched by debates on diversity and difference in cities, including gender (Levy, 2013).

Research on female mobility worldwide shows that women are far more likely to be involved in caregiving-related travel, such as picking up or dropping off household members, health-related trips, and social visiting purposes (Ravensbergen et al., 2022; Sweet & Kanaroglou, 2016). Having children in the household increases the probability of women making these types of trips due to socio-cultural roles traditionally attributed to them, in which particularly mothers spend considerable time transporting children (Havet et al., 2021; McDonald, 2006). Research has also shown that caregiving and household maintenance trips lead to women performing complex spatio-temporal activity patterns, for which public transport does not necessarily cater, as it is usually planned for home-Central Business District (CBD) connections and morning peak schedules (Ng & Acker, 2018). Thus, women tend to spend more time in traffic and congestion, and experience the stress of arriving on time for an array of activities, which has been shown to put them at higher risk of negative mental health effects associated with traveling (Higgins et al., 2018). In fact, Scheiner and Holz-Rau (2017) found that having young children has significant positive effects on women's activity pattern entropy (a measure of activity pattern complexity), but less so on men's, supporting the well-known notion that having children mainly affects mothers' rather than fathers' activity patterns. With regards to household structure, the same authors found that living with a partner decreases women's activity pattern, but not men's, and reduces tour complexity for both genders. These findings suggest that intra-household worksharing which, according to the authors, may reduce women's entropy as a result of women taking on household and family caring roles while giving up employment. In that line, Susilo and Avineri (2014) found that men have more time to spend on out-of-home activities than their counterparts. A study in Mumbai, India, showed that graduate students and young professionals have fewer differences in travel preferences by gender. However, time limitations and physical safety are

experienced and expressed differently by each gender, with, for example, women focusing on safety more than on time constraints (Shirgaokar, 2019).

The gendered division of household activities often results in lower employment rates and more limited job choices for women. Their job opportunities are more spatially constrained by choosing job locations that are easy to commute to/from so that they can manage their household and caregiving responsibilities (Blumenberg, 2007; Kwan, 1999a). They also are more likely to have part-time and lower-paid jobs (Havet et al., 2021). Furthermore, women are more likely than men to work closer to home (in places as Haifa, Israel; Seoul, Korea; Baltimore and Worcester, USA; urban areas in Italy; and the Netherlands) and at home (USA), less likely to have a mobile workplace, to engage in work-related overnight travel , and more prone to start businesses located closer to home (all three in the USA) (Hanson, 2010). Given the contexts where these research has been carried, could be a tendency in the Global north or North America. Research has shown that employed women travel shorter distances to work than men, despite their commute times being almost the same (Hanson & Johnston, 1985; Ng & Acker, 2018; I. Olmo Sánchez & González, 2014), implying lower speeds, which can either be due to slower modes of transport (walking) or less efficient public transport routes.

In regards to transport mode choice, in diverse contexts such as the United States and China, women tend to use public transport or taxis more intensively than men (McGuckin & Murakami, 1999; Ng & Acker, 2018; Ta et al., 2022), and to use slower travel modes, such as walking (Havet et al., 2021). In fact, a statistical analysis using population-representative travel surveys from 19 major low and middle-income cities across 13 countries showed that women are, on average, 25% more likely to walk to work than men, whereas cycling is a mode chosen more by men (Goel et al., 2022). Certain life events influence mode choice, such as having children, a reason for which many households tend to switch their transport mode to private vehicles for comfort and flexibility (McCarthy et al., 2017). However, a study in Rhône-Alpes (France) found that having access to a car in the household increases men's mobility more than women's, given that they are still the primary care givers in the household (Havet et al., 2021). Considering socio-economic status, women with a higher socio-economic status tend to cycle more, which indicates that women generally ride their bicycles by choice rather than necessity (Yuan et al., 2023). On the contrary, women with a low socio-economic status may walk more by necessity due to a lack of alternate modes of travel, poor public transit conditions, and poor home-work balance (Yuan et al., 2023).

Research also shows that the most educated women (Bachelor's degree level or higher) are able to limit household responsibilities by subcontracting some of them, and a high level of education accentuates car use among women compared to low-income women (Havet et al., 2021).

In Canada, research shows that women are more likely to chain trips, travel at mid-day or off-peak times, have shorter distance trips for serving others, and are more likely than men to use public transit on their commute (Babbar et al., 2022). An analysis of Canada's 2015 General Social Survey showed that women who spend time working/getting an education experienced a relative increase of driving time relative to men, while gender apparently was not determinant of mode choice, and, in one-car households, gender was not strongly linked to which partner had primary access to the vehicle (Shirgaokar & Lanyi-Bennett, 2020). A 2001 data analysis from the Québec City Metro area found that when controlling for mode of travel and socio-demographics, women and men had essentially the same work trip distances (Hanson, 2010). This differs from what is usually found in gender and transport, leading the authors to point out that quantitative studies of how gender shapes mobility might not elucidate enough if they are not analyzed from a context-specific perspective, while also highlighting the need to collect primary data (Hanson, 2010). Previous research shows that in Montréal, women complete 58.2% of all daily mobility of care trips, and the gendered distribution of mobility of care is more inequitable in households with children (Ravensbergen et al., 2023).

Transportation research in general has a spatial component of geolocated data, however, more advanced spatial analysis on the gendered relations of travel are not always performed. In a study in Santiago, Chile used three months of anonymized mobile phone records, census data, GTFS (General Transit Feed Specification) data, and Points of Interest (POI) data (Gauvin et al., 2020). The analysis revealed a gender gap in mobility: women visit fewer unique locations than men, and by mapping this mobility gap over administrative divisions, it found a wider gap associated with lower income and lack of public and private transportation options. A qualitative analysis by Gollaz Morán (2022) applied trajectory mapping by talking to women about their trajectories: starting and destination points, time spent by mode, and the type of trajectory; gendered and embodied feelings, and, strategies they use (personal and/or collective). Then, relief maps were created as a systematic tool to understand how subjectivity is constructed.

While many studies worldwide have looked at the differences in mobility patterns between men and women, fewer have adopted a quantitative spatial perspective. Additionally, to the authors' knowledge, less studies have generated differentiated models for men and women to examine how the influence of key determinants varies across genders. Also, there are fewer updated studies on gender and mobility in the Canadian context with the most updated data available, Ravensbergen et al. (2023) being one of them. This contribution addresses those gaps.

5.3 Methods

5.3.1 Study Area

The Montréal Census Metropolitan Area (CMA) has around four million residents and is divided into eight main regions (**Figure 5.1**). The economic and commercial activity centre is Centre-Ville (downtown), where there are both higher population densities and job densities and can be seen as the Central Business District (CBD) of the city. The Centre area is also dense and has high job and commercial activity, and acts as a buffer between the CBD (Centre-Ville) and the more residential areas. The Est (east) and Ouest (west), Laval, and Longueuil regions are suburban with some mixed-use areas, while in the rest of the territory (Couronne Nord and Couronne Sud), the character is predominantly suburban. This paper focuses on the six central regions with the highest population density (Centre, Centre-Ville, Est, Ouest, Laval, and Longueuil), leaving out Couronnes Nord and Sud. Their large area and low population density mean they are ruled by different spatial and social logics than the rest of the Montréal CMA. The population of Montréal agglomeration, Laval and Longueuil represents 72.42% of the total of the Metropolitan Area, while the Couronne Nord 14.84%, and the Couronne Sud 12.74% (Statistics Canada, 2017).

The predominant mode of transport is the car. As of 2018, 63.4% of commuters travelled to work by car (ARTM, 2018). The transport system network in the city is composed of four metro lines serving mainly the central areas, and numerous bus lines with varying frequencies throughout the territory. Commuter rail connecting suburban zones to the central neighbourhoods are also available during peak-hours. The city also has a strong bike-share system and paratransit services.

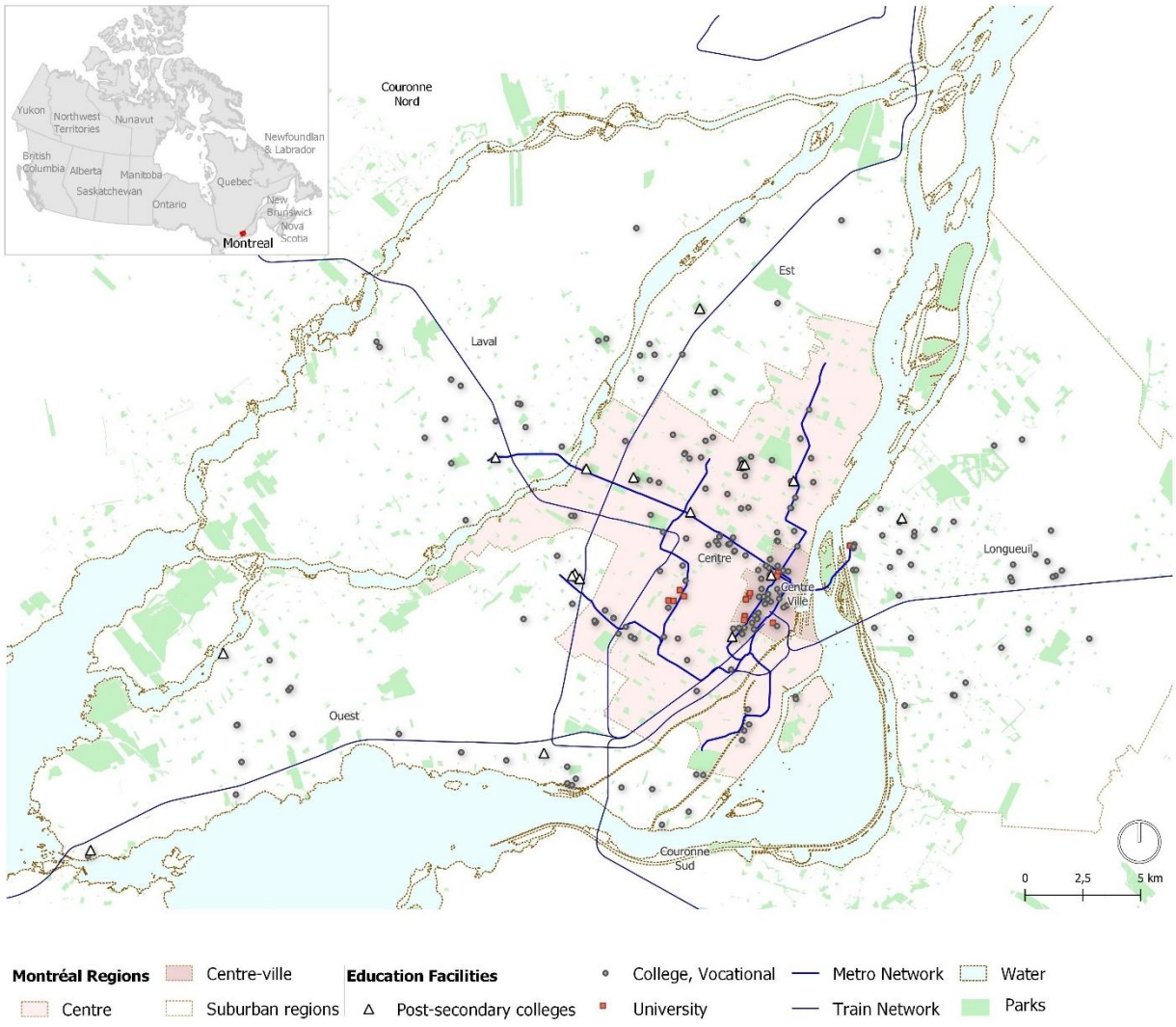

Figure 5.1 Montréal Region

5.3.2 Data and Variables

This work uses the Montréal Origin-Destination (OD) household survey of 2018. The survey samples about 5% of the city's population to record their travel diaries during one non-holiday weekday in the Fall. The survey collects household information, personal information and trip information. To obtain the distance of each trip, the OpenStreetMap Road Network was used. Network distances for each trip were computed using GRASS GIS (Grass Development Team, 2025). All statistical analyses are performed in R (R Core Team, 2025) and spatial processes in QGIS (QGIS.org, 2025).

The variables considered in this study are presented in **Table 5.1**. Trip *Mode* considered the four main modes of travel (as there were not enough observations from other modes): car, public

transport, walking and bicycle. Trip *Purpose* also considered the categories with the highest number of observations: health, leisure, trips accompanying others, studying, shopping and work. For this study, the purposes of picking up or dropping of someone were joined together as "Accompanying Trips". The variable *Kids at Home* was obtained by counting the number of people under 18 in each household. For the variable *Parental Structure*, as the survey does not provide specific information about parenthood, and to avoid biases and assumptions about the diversity of possible parental structures, the variable was estimated by counting the number of adults in households with children, and segmenting households as mono-parental (only 1 adult), more than one adult, and no children. Finally, *Car Ownership* is also included, as the literature shows that car ownership is an important determinant of travel behaviour, with three categories: no car, one car and more than one car. The variable *Region* is based on the eight regions defined by the Autorité Régionale de Transport Métropolitain, and the region is assigned based on the location of the trip origin.

5.3.3 Modelling and Analysis Processes

The hypotheses that guide the modelling approach are that travel patterns, and distance in particular, vary between women and men, initially pointing to women being more spatially constrained than men, and that these differences can manifest numerically, but also in the functional sense of urban space. This means that spatially, it is expected that certain areas will have more trips made by women, probably related to land use characteristics. To analyze gender differences in trip distances and spatial patterns, three complementary approaches were chosen for all trips made by people over 18 years old, given that underage people are not allowed to drive, and their travel might be ruled by different logics. The first one is a descriptive statistical analysis of trip distances classified by gender, focusing on mode and trip purposes, and socio-economic characteristics (income level of the household, presence of children at home, location of the household within Montréal's regions, parental structure of the household) using central trend measures, ANOVA, and a first linear regression to test the significance of gender.

The second process is to model data using a linear regression with distance as the dependent variable as a function of trip, individual and household characteristics, and region of origin of the trip. The dependent variable (distance) showed a highly left-skewed distribution, and so for the regression it was decided to work with the logarithm of the variable to have a distribution tending

more to normality. Consequently, the percentage effect of each category on the dependent variable is interpreted as the equation:

$$Effect = (exp(Estimate) - 1) * 100 \quad (5.1)$$

As presented in **Table 5.1**, the base category for all the categorical explanatory variables is based in most cases on the criteria of representativeness, meaning having the highest number of observations. For the regression, *Mode of travel* is not included in the model since it is endogenous to distance. *Children at home* was also left out of the model for its high collinearity with *Parental Structure.* A test was made by grouping trip purposes to have fewer categories, but all these tests had lower R-squared values and showed statistically significant lower Likelihood-Ratio performance. Therefore, the full model with all categories and variables was chosen, as it is shown to be more informative.

A preliminary regression was run with all explanatory variables, including gender as an independent variable. The results demonstrate that gender is significantly associated with trip distance while controlling for other variables, with women tending towards shorter distances. These preliminary findings indicate that analyzing effects by gender is pertinent. From this, we ran two separate models for men and women to assess the distinct effect of the explanatory variables across genders. Due to the large sample size (96444 trip observations for women and 88442 for men), all variables tended to be statistically significant, creating a misleading and homogenizing result for explanatory variables (van der Laan et al., 2010). The regression was then carried out by bootstrapping 1000 subsamples of size equal to the original samples (Fox & Weisberg, 2018), obtained by random resampling with replacement. The estimates obtained by this bootstrap procedure were then used to calculate the confidence intervals of the regression coefficients. Such confidence intervals were used as a more reliable measure of significance for variables in large samples. Further, the confidence intervals obtained for men and women were compared to examine whether the effects are different across gender. This modelling approach of separate models for regression in gender research has been used before by Clifton and Livi (2005).

The third approach seeks to examine the spatial behaviour of women's travel as compared to men's travel, with the purpose of exploring if general patterns can be identified, of areas being occupied distinctively by women and men. For this, trip destinations in the OD survey were geo-located and aggregated by counting them for each Census Tract (CT), used as a spatial unit of analysis. Then,

the percentage of women's trips (number of women's destinations/sum of men and women's destinations) was computed to identify which areas exhibit a difference of gender patterns in the distribution of trip destinations. After, both global and local spatial autocorrelation indexes were fitted in GeoDa (Anselin et al., 2006), with a Kernel distance matrix with a threshold of 3600 m. This corresponds to the distance for which every CT has at least one neighbour, which is one of the most recommended criteria in the case of polygons of highly variable sizes, such as CTs (Anselin, 2002; Anselin & Rey, 2014; Getis & Aldstadt, 2004). The reason to use global and local spatial autocorrelation tests is that it allows for identifying groups of locations with similar values. As the variable under investigation is the percentage of women's trips, groups of regions with high values imply higher percentages where women have travelled, which can indicate areas that attract more women. To understand areas' characteristics, we have visually described the areas in terms of the land use types. Given the exploratory nature of this analysis, it is not possible to infer causation or perform a detailed analysis of the relationships between locations' characteristics and predominance of women, but it serves as a starting point to shed light on the urban characteristics that could relate to different gender travel patterns.

Table 5.1: Summary statistics.

Variable	Type	Comments	N Man	N Woman
Distance				
[2]*Distance*	*Dependent*		*36,969.00*	*39,623.00*
Mode (Not included in the regression analysis)				
Car			*24,902.00*	*25,350.00*
Walking			3,516.00	4,386.00
Public Transport			7,478.00	9,202.00
Bicycle			1,073.00	685.00
Trip Purpose				
Health	Comparison		1,116.00	1,674.00
Leisure	Comparison		4,565.00	4,965.00
Studying	Comparison		2,127.00	2,369.00
Shopping	Comparison		6,793.00	8,444.00
Visit	Comparison		1,520.00	1,778.00
Accompanying trip	Comparison		5,589.00	6,347.00

[2] The number of observations has been reduced (originally 96,444 trip observations for women and 88,442 for men) because the purpose of *returning home* was excluded from the analysis.

Table 5.1: Summary statistics. (continued)

Variable	Type	Comments	N Man	N Woman
Work	*Base*		*15,259.00*	*14,046.00*
Children at Home (Not included in the regression analysis)				
No Child			*24,183.00*	*25,129.00*
Small Child		< = 12 years of age	10,047.00	11,322.00
Teenager		> 12 <= 17 years of age	2,739.00	3,172.00
Parental Structure				
No Child	*Base*		*24,183.00*	*25,129.00*
Mono-parental	Comparison		1,424.00	2,481.00
More than 1 adult	Comparison	More than 1 adult in the household	11,362.00	12,013.00
Income Level				
Low	*Base*	*Household income < 60,000 CAD*	*12,073.00*	*14,719.00*
Middle	Comparison	Household income >= 60,000 <= 150,000 CAD	18,725.00	19,040.00
High	Comparison	Household income > 150,000 CAD	6,171.00	5,864.00
Region				
Centre	*Base*		*14,232.00*	*15,568.00*
Centre-Ville	Comparison		2,378.00	2,082.00
Est	Comparison		3,517.00	3,753.00
Laval	Comparison		4,886.00	5,339.00
Longueuil	Comparison		5,716.00	6,331.00
Ouest	Comparison		6,240.00	6,550.00
Car Ownership				
1 Car	Comparison		4,283.00	5,130.00
More than 1 Car	Comparison		16,166.00	17,688.00
No car	*Base*		*16,520.00*	*16,805.00*

5.4 RESULTS

This section presents the results obtained for the central trend measures, the linear regression analysis, and the spatial analysis in a succinct manner, while reflections and implications are presented in the Discussion section.

5.4.1 Central Trend Measures and descriptive statistics

The central trend measures for trip distance are presented in **Table 5.2.** The results show that**,** in general, the median trip distance of women is less than that of men (87% of it), and this is a trend that prevails when the analysis is segmented by trip and individual characteristics and by region. The primary statistical analyses indicate, regarding mode of transport, that women's trips are 16% shorter in median distance than men by car, 3% less by walking, 4% less by public transport, and 8% less by bicycle. Regarding trip purpose, women travel 3% less for health and 7% less for both leisure and accompanying trips, 13% less for visits and 15% less for work; while travel 2% and 5% more for studying and shopping, respectively. As for the presence of children in the household, women with no children travel 9% less than men, while the distance of women with small children is 25% shorter than for men, and women with teenagers travel 15% shorter distance than men. As for the parental structure, women in households with no children travel 11% less than men, while women in mono-parental households travel 29% less than men. In households with more than one adult, women travel 21% less than men. When considering income, at the high, middle, and low levels, women travel 8, 12 and 14% less distance than men. As for the region of the trips, women travel 12% less than men in the region Centre, while they travel 7% more in Centre-Ville. Women also travel 18%, 17% and 18% less than men in the Est, Laval and Longueuil regions, while the difference is starker for the Ouest region, where women travel 22% less than men. In households with no car women have a median trip 4% shorter than men, 9% shorter in households with one car, and 16% shorter in households with more than one car.

Table 5.2: Central trend measures and percentage of variation in trip distance for variables.

Variable	Median Distance Men (m)	Median Distance Women (m)	% of Variation Women vs. Men	N Trips Man	N Trips Woman
All	5793.774	5018.402	87%	36969	39623
Mode					
Car	6413.3407	5407.4731	84%	24902	25350
Walking	847.7983	789.0062	93%	3516	4386
Public Transport	7701.3289	7356.7805	96%	7478	9202
Bike	3246.4804	3001.1458	92%	1073	685
Purpose					
Health	5280.608	5143.038	97%	1116	1674

Table 5.2: Central trend measures and percentage of variation in trip distance for variables. (continued)

Variable	Median Distance Men (m)	Median Distance Women (m)	% of Variation Women vs. Men	N Trips Man	N Trips Woman
Leisure	3866.221	3587.574	93%	4565	4965
Studying	7769.455	7907.78	102%	2127	2369
Shopping	2728.173	2862.727	105%	6793	8444
Accompanying trip	6500.46	6036.913	93%	1520	1778
Visit	3481.153	3039.278	87%	5589	6347
Work	9239.927	7874.703	85%	15259	14046
Children at home					
No Child	5524.113	5040.647	91%	24183	25129
Kid	5928.227	4435.819	75%	10047	11322
Teen	8095.446	6862.356	85%	2739	3172
Parental Structure					
No Child	5524.113	5040.647	91%	24183	25129
Monoparental	6171.913	4400.92	71%	1424	2481
More than 1 adult	6470.226	5098.247	79%	11362	12013
Income level					
Low	4689.787	4019.099	86%	12073	14719
Middle	6374.471	5609.096	88%	18725	19040
High	6666.514	6163.444	92%	6171	5864
Region					
Centre	4557.053	4030.885	88%	14232	15568
Centre-ville	2527.51	2715.961	107%	2378	2082
Est	6739.436	5545.522	82%	3517	3753
Laval	9907.734	8183.591	83%	4886	5339
Longueuil	6913.099	5699.112	82%	5716	6331
Ouest	7905.011	6197.539	78%	6240	6550
Car Ownership					
No Car	3187.783	3044.927	96%	4283	5130
1 Car	4890.845	4453.684	91%	16166	17688
More than 1 Car	8051.064	6748.575	84%	16520	16805

The full regression that includes gender as a variable (**Table 5.3**) showed that gender is a highly significant variable ($p < 0.001$), and that the effect for women on distance is negative, meaning that women tend to travel smaller distances than men. These results demonstrate the need to understand

the differentiated effects of the other variables on distance, to have a deeper perception of how different factors specifically affect women's travel. All the other variables (and categories) showed statistical significance and are thus included in the following analyses. Additionally, an ANOVA test was run with parental structure, trip purpose, car ownership, income level, and region. Results show a significant p-value for all variables at the 99% confidence interval, implying that there are significant differences in distances travelled when comparing the different categories for each variable. For the category of studying trips, despite the fact that it does not show significance, it

Table 5.3: General regression model.

		Model Diagnostics				
		Residual Std Error 0.43 on 76573 deg. of freedom				
		Mult. R2: 0.23		Adjusted R2: 0.23		p <0.001
Category	**Category**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Sig.**
	(Intercept)	3.615236	0.005595	646.098	<0.001	***
	Health	-0.153441	0.008639	-17.761	<0.001	***
	Leisure	-0.294241	0.005163	-56.992	<0.001	***
	Studying	-0.010197	0.006954	-1.466	0.143	
	Shopping	-0.411212	0.004439	-92.637	<0.001	***
Trip purpose	*Accompanying Trip*	-0.36117	0.004882	-73.981	<0.001	***
Base cat: Work	*Visit*	-0.0977	0.008008	-12.2	<0.001	***
Parental Structure	*Mono-parental*	-0.015025	0.007353	-2.043	0.041	*
Base cat: No children	*More than 1 adult*	-0.043992	0.003788	-11.613	<0.001	***
Income	*High*	0.048602	0.005214	9.321	<0.002	***
Base cat: Low income	*Middle*	0.042178	0.003718	11.344	<0.003	***
	Centre Ville	-0.0706	0.006995	-10.093	<0.004	***
	Est	0.134168	0.005777	23.224	<0.005	***
	Laval	0.231294	0.005183	44.621	<0.006	***
Region	*Longueuil*	0.138451	0.004833	28.646	<0.007	***
Base cat: centre	*Ouest*	0.17259	0.004743	36.389	<0.008	***
Car Ownership	*1 car*	0.128791	0.005304	24.28	<0.009	***
Base cat: No car	*More than 1 car*	0.222077	0.005863	37.879	<0.010	***
Gender **Base cat: Men**	***Women***	**-0.033388**	**0.003145**	**-10.615**	**<0.011**	***

Signif. Codes: 0 '***', 0.001'**', 0.01 '*', 0.05 ' .'

has been decided to keep the variable for the rest of the regression, for being an important element for urban planning.

5.4.2 Regression Analysis

The aim of this analysis is to determine the differentiated effects of key variables on how women and men move, with an initial assumption that women are more spatially constrained based on parental structure and income level. The results of the regression analysis modelling the trip distance for men and women are presented in **Table 5.4.** All explanatory variables are significant at the 95% confidence level. With Work as the base category for trip purpose, the other trip purposes are associated with shorter trips (negative coefficient), except for studying trips for women. For all the other variables, the direction of the relationship is the same for men and women. For the parental structure, being in a household with children (mono-parental or more than 1 adult) results in shorter trips than for the base category, which is No children. As for income, being in a middle- or high-income household is associated with longer trips compared to trips made by individuals in low-income households. As for the region, trips made from the Centre-Ville are shorter than the base category (Centre), while the trips made from the Est, Ouest, Laval and Longueuil regions are longer. Finally, owning a car (1 car or more) implies longer trips compared to trips made in households without a car.

Table 5.4: Results for bootstrapped linear regression.

		Women				**Men**			
Variable	**Category**	***Estimate***	***5%***	***95%***	***Effect***	***Estimate***	***5%***	***95%***	***Effect***
	(Intercept)	3.573	3.562	3.585		3.622	3.610	3.635	
	Health	-0.123	-0.141	-0.106	-11.596	-0.189	-0.212	-0.168	-17.256
	Leisure	-0.279	-0.291	-0.268	-24.373	-0.308	-0.320	-0.295	-26.482
	School	0.028	0.015	0.041	2.872	-0.049	-0.063	-0.035	-4.757
	Shopping	-0.372	-0.383	-0.362	-31.092	-0.454	-0.466	-0.443	-36.507
	Acompanying Trip	-0.346	-0.358	-0.333	-29.244	-0.373	-0.384	-0.361	-31.106
Motive	*Visit*	-0.081	-0.100	-0.061	-7.747	-0.114	-0.135	-0.093	-10.765
Parental Structure	*Monoparental*	-0.023	-0.040	-0.008	-2.301	-0.006	-0.025	0.014	-0.563
	More than one Adult	-0.061	-0.070	-0.052	-5.945	-0.028	-0.037	-0.020	-2.795
	High Income	0.071	0.059	0.083	7.385	0.027	0.015	0.039	2.776
Income	*Middle Income*	0.048	0.039	0.057	4.895	0.037	0.028	0.046	3.799

	Centre-Ville	-0.034	-0.055	-0.014	-3.339	-0.102	-0.121	-0.082	-9.669
	Est	0.127	0.113	0.141	13.572	0.142	0.128	0.156	15.234
	Laval	0.225	0.213	0.237	25.291	0.238	0.226	0.250	26.835
	Longueuil	0.133	0.122	0.143	14.211	0.145	0.134	0.156	15.626
Region	*Ouest*	0.164	0.153	0.175	17.814	0.181	0.170	0.192	19.845
Car ownership	*1 Car*	0.124	0.112	0.136	13.204	0.134	0.121	0.146	14.288
	More than 1 Car	0.211	0.198	0.225	23.506	0.233	0.219	0.247	26.227

Figure 5.2 illustrates the regression coefficients with their confidence intervals to highlight which coefficients are different between women and men. Several variables exhibit non-overlapping confidence intervals (suggesting significant difference between genders). First, with respect to trip purpose, the association between making a study trip (as compared to a work trip) and the dependent variable is inverse for men and women. Studying trips for women are 2.87 times longer trips than for work, whereas the same category for men shows their trips for studying are 4.75 times shorter than for work. As for health, leisure, accompanying, visit and shopping trip purposes, the effect is negative for both genders, but greater for men than for women, meaning the reduction of distance compared to work is greater for men. Health trips for women are 11.5 times shorter than for work, while for men they are 17.3 times shorter. Shopping trips have an effect of 31 times shorter trips than to work for women, while for men they are 36.5 times shorter. For accompanying trips, women experience a reduction of 29.2 times the distance they travel for work, while men experience a 31.9 times reduction of distance compared to work. Leisure trips show a smaller difference between genders, with a reduction varying from 24.4 to 26.5 shorter trips than for work.

As for the parental structure, the relation between distance and being in a household with children with more than one adult, as compared to being in a household without children, is different for men and women. Women in households with children with more than one adult showed a decrease of 5.9 times the distance in trips compared to women in households with no children, while for men this reduction is 2.8 times. This suggests that the reductive effect of children on distance is larger for women than for men, notably when there are other adults present in the household.

With respect to income, the high-income category shows different effects for men and women as compared to the low-income category. Women in high-income households travel 7.4 times longer than in low-income households, while men travel only 2.8 times longer than men in low-income

households. Owning a car or more than one car showed no difference in the distance reduction effect between men and women, as both intervals overlap.

For the effect of region, the distance reduction effect is greater for men than for women, and the difference is statistically significant for the Centre-Ville sector. Women in Centre-Ville experience a reduction of 3.3 times the distance they travel than those who live in Centre, while men experience a reduction of 9.7 times the distance they travel. There is no significant difference between men and women for the other sectors.

Finally, is it important to note the categories for which the difference of the coefficients between men and women is not statistically different (overlapping confidence intervals) when compared to the base category: trips made for visiting purposes, trips made by individuals in mono-parental households, in middle-income families, or in households with one or more cars, and trips originating in the regions Est, Ouest, Longueil and Laval.

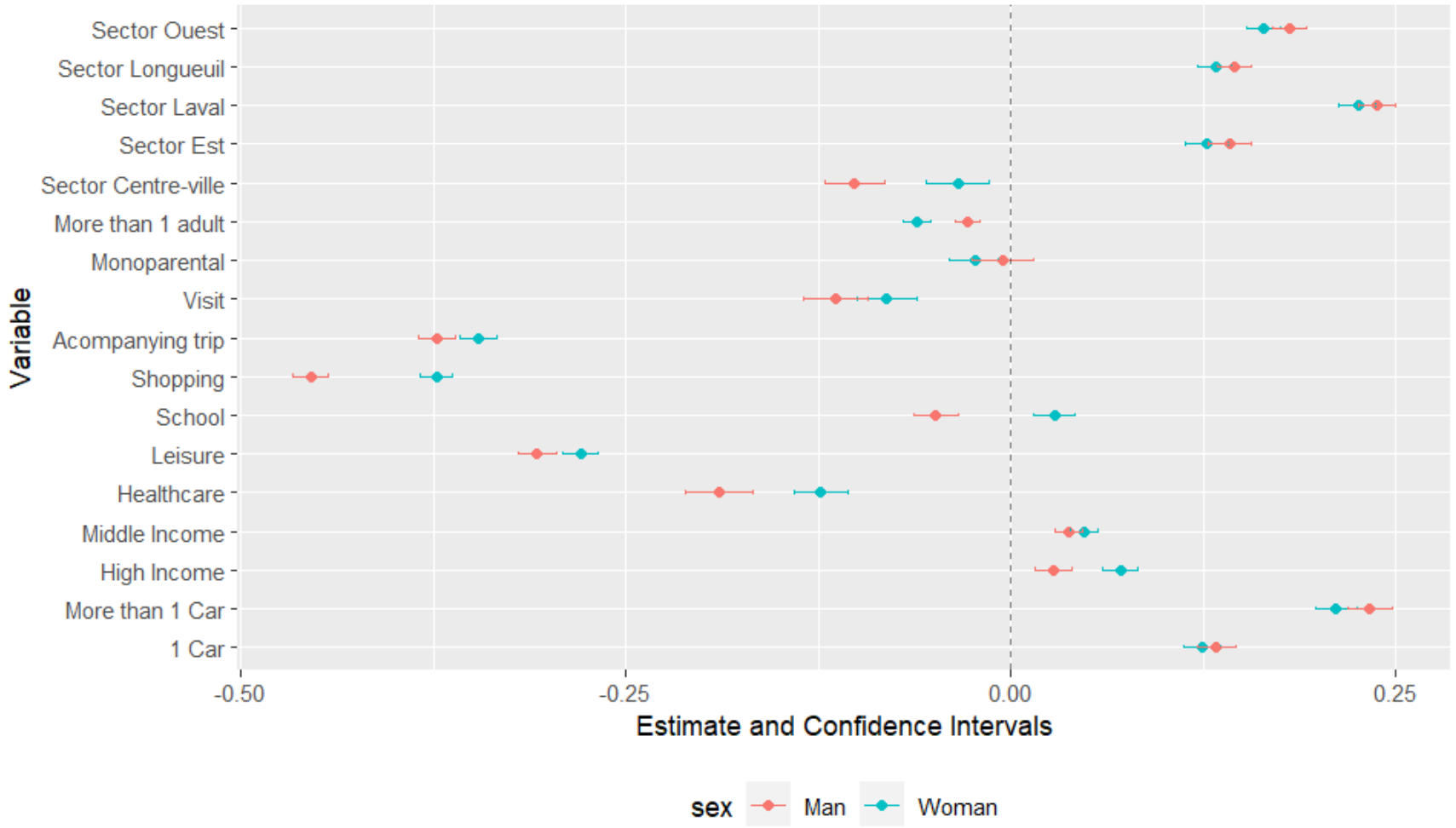

Figure 5.2 Bootstrapped linear regression coefficients by gender.

5.4.3 Spatial Analysis

The analyses for Moran's Global Index produced no significant results for any of the trip purposes ($r^2 < 0.1$), meaning that there is not enough evidence to reject the null hypothesis of random distribution in spatial terms for gender and trip purposes. However, it is necessary to highlight that when Local Indices of Spatial Autocorrelation were run, significant clusters were found for work, leisure, studying, and accompanying purposes, meaning in the first instance that the phenomena is of local geographic scale. Patterns of High-high percentage clusters (higher percentage of women) and Low-low clusters (higher percentage of men) were found, allowing for the detection of areas where more women are going than men, and vice-versa. While all purposes were run in this manner, in this section we report those with significant local autocorrelation, illustrated in **Figure 5.3**. It is important to highlight, for the appropriate interpretation of results, that clusters with higher percentage of women are those with a percentage of female trips above the mean and with neighbouring CTs that are also above the mean. Thus, more than absolute predominance of women/men trip destinations in a given CT, these analyses show distinct distributions of gender patterns.

Commencing with the four general maps (work, leisure, studying and accompanying) displayed on the left, the main trend obtained was of central vs. suburban nature. The clusters in orange show groups of CTs with a higher percentage of women, while clusters in green show groups of CTs with a higher percentage of men. Clusters with a higher percentage of men tended to locate more around the central areas (Centre-Ville especially), while clusters with a higher percentage of women were found mainly in the suburban areas. This trend was observed for work, leisure and accompanying trips.

In the case of work trips, higher percentages of women concentrate more in Laval and Longueuil (immediate suburban municipalities). On **Figure 5.3**, maps Work A1-A2 show the work-related land uses in these areas, that are useful for visual exploratory purposes. The dots represent the locations of different categories of land uses (industry, commercial, health services). Other categories were tested, but only those that showed an association with the location of the clusters were displayed. Darker colors of land uses imply higher concentrations of a given category, as the dots superpose. Clusters with a higher proportion of women showed a predominance of commercial

land uses (Work A1), while in the clusters of higher proportion of men (Work A2), a stronger presence of industrial land uses were observed as compared to the women's clusters.

As for leisure trips, the pattern shows more dispersed clusters, while for accompanying trips, the trend was more compact. Namely, we observed a cluster of higher percentage of men in the CBD-Central areas, and scattered clusters of higher proportion of women in the suburban areas. Conversely, in the case of studying trips, higher percentages of women were found in the Centre region, in a district characterized by universities and post-secondary colleges. In the case of men, a higher percentage is observed in clusters dispersed across the territory, close to professional training centres. The exploration of land uses was less evident for leisure and studying trips, which is why it is not mentioned in the section, keeping the stronger trend relating to the location of urban centrality.

Overall, the results tend to demonstrate that there exist distinct spatial patterns between men and women, which seems to be mostly associated with a central-suburban dynamic, as well as with predominant land use characteristics (e.g., presence of specific institutions). Future studies could build on the present findings to further examine the land use and transport characteristics of the destination clusters for women and men. Furthermore, future data collection approaches should be investigated to enable more fine-grained analyses from a spatial perspective.

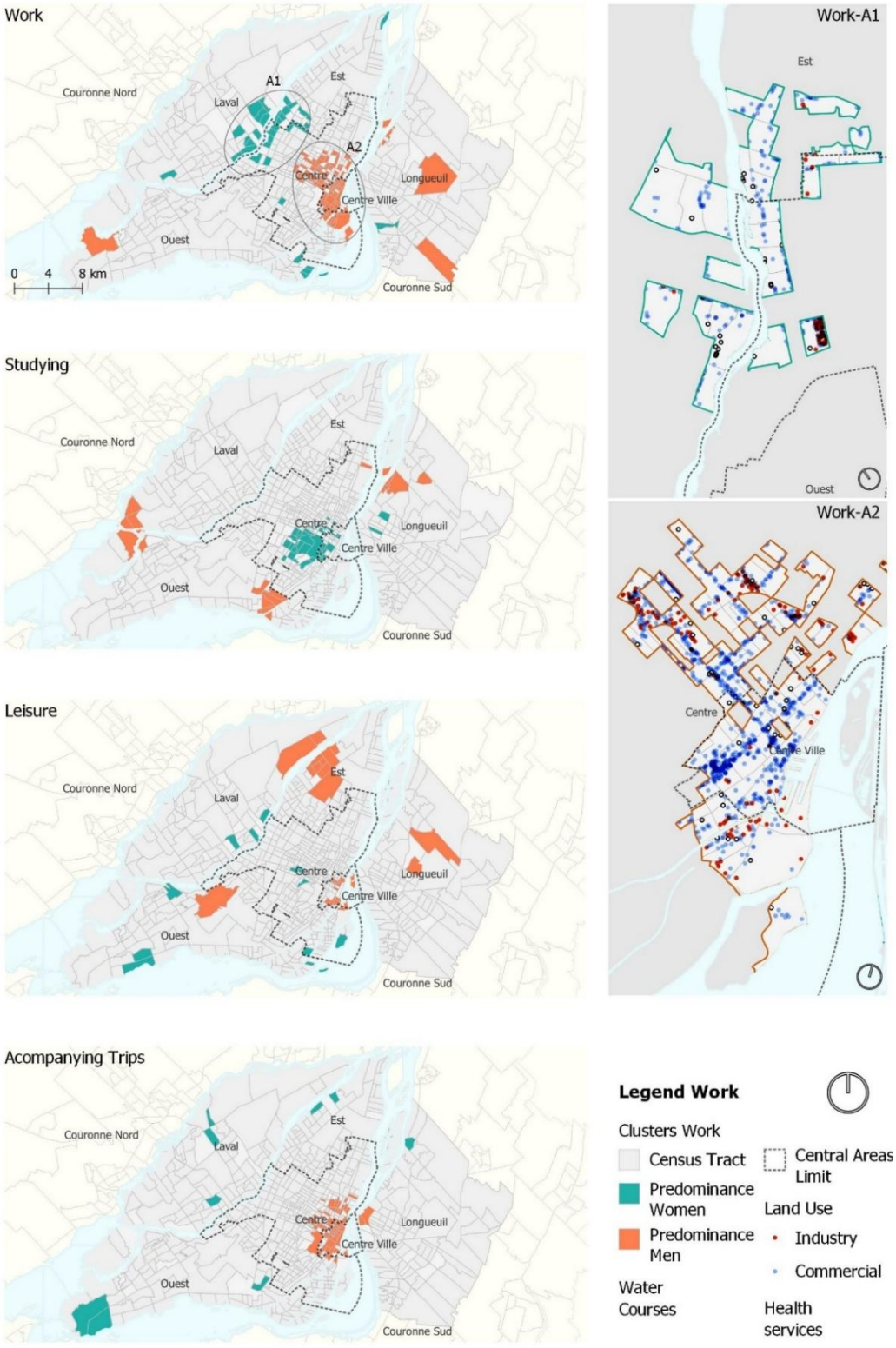

Figure 5.3 Local Spatial Autocorrelation clusters for Trip Purpose Destinations.

5.5 Discussion

Walking and public transport seem to be the modes where there is more equality between genders, while by car (distance) and bicycle (trip counts) the difference is greater[3]. This agrees with the literature, which explains that women's lower total and commute daily distances are attributable to women's job status (gendered division of household roles) and to their reduced access to a private car and feelings of insecurity as bike riders (Goel et al., 2022; Havet et al., 2021). As for the trip purpose, work trips seem to be where the difference in distance is larger between men and women, which might confirm that women seek jobs closer to home to be able to fulfil gendered roles traditionally assigned to them in the household, as is seen in the literature (Havet et al., 2021). This is supported by the results of the regression analysis that show the effect of distance reduction as a result of trip purpose (other than work) was larger for men. In other words, it suggests that the difference in distance between work trips and other trips is greater for men than women, when other variables are controlled for.

The findings suggest that the presence of children has a greater effect on women. The descriptive statistics showed that women with small children travel 25% less than men, and women in mono-parental condition travel 29% less than men in the same condition. The regression results for this variable show that women's distance in households with more than one adult is 5.9 times smaller compared to women in households with no children, while for men this reduction is 2.7 times. This suggests that the reductive effect of children is larger for women than for men, even in the presence of other adults in the household. This supports the idea that still they are the primary caregivers in the household, which affects their daily mobility (Havet et al., 2021; McDonald, 2005, 2006; Ravensbergen et al., 2023; Rosenbloom, 2006; Sweet & Kanaroglou, 2016).

The study indicates that income plays a role in gender differences. Women in high-income households travel only 9% less than men, while in middle- and low-income households, the difference is larger, going up to 12 and 14% respectively. This is one of the most surprising findings, as in other geographic contexts, gender differences are stronger in lower socio-economic conditions (Lecompte & Bocarejo, 2017), given that people from lower socio-economic status are

[3] **Table 5.2** showed that in trips made by car, the gap of distance travelled is larger, as women's average distance is 84% shorter than men's. When considering trip counts, women's trips by bike are 63% of men's trip counts. Walking and public transport show a smaller gap between men and women in both distance (gap 4%-6%) and trip counts (women make 1.25 times more trips than men with both modes).

forced to live farther from the city centre and in not necessarily well-served areas, which exacerbates gender inequalities (Lecompte & Bocarejo, 2017). In addition, the regression analysis revealed that women in high-income households travel 7.4 times longer than women in low-income households, while men travel 2.7 longer than men in low-income households. The fact that the effect on distance of women in high-income households is larger than on men compared to those in low-income households might indicate that women still carry housework duties, but their more privileged condition allows them to use private vehicles to perform their activities in farther places (Blumenberg, 2020). These results highlight the importance of context-specific factors.

Geographic location also has an effect on gender travel differences. In central areas, the difference in distance travelled is significant between men and women, while in suburban regions it is not. However, women still travel less than men. In spatial terms, women end up having a more limited space for daily action, despite their location.

Importantly, there are some socio-economic factors where there are no perceivable disparities between genders. The linear regression showed no significant differences between men and women for mono-parental and middle-income households, which suggests that the routines and practices in these kinds of homes may force a condition of more equity between genders. This is consistent with the literature that finds that the spouse/partner's presence exacerbates the effect on gender differences in work travel in households with children (Fan, 2017), and that greater household income causes an increased gender gap in travel (M. I. Olmo Sánchez & González, 2016). Also, owning or not owning cars seems to produce no difference between the distances travelled by men and women, which supported by some studies which have found some convergence in the gender gap in areas where private transport use is more widespread (highlighting a geographical implication) (Cubells et al., 2020a).

The spatial analysis establishes that there are different gender patterns in the distribution of trip destinations in diverse spaces of the city, mainly following a trend of suburban destinations for women and central destinations for men. These findings emphasize the need to consider gender explicitly when performing transport analyses. Women travel more in suburban or residential areas for tasks like accompanying other members of the household, which seems to spatially demonstrate the perpetuation of traditional gender roles, and supports the finding that women's daily movement is more spatially limited. A study on the same dataset found that women complete the bulk of

caring tasks (Ravensbergen et al., 2023), while this research has shown that women's distance is shorter. Both findings together imply that women spend time in smaller radiuses than men likely due to caregiving tasks. These findings confirm that the current division of labour has significant impact on travel patterns and might have implications on women's quality of life. Further, identifying *where* women travel can inform more equitable transport policies and networks. This research has attempted to identify the categories of land uses of the destination areas, however, deeper research on the topic is necessary.

5.6 Conclusion

This contribution looked at the differences in travel patterns between men and women in the Montréal region from a spatial point of view, to find how spatial travel patterns vary between men and women, and how travel-influencing factors affect men and women differently The main results indicate that women travel shorter distances for all purposes and with all modes, with women's trips being more local than men's. Further, differences between genders are most visible among lower-income groups and in suburban areas, while the presence of children in the household reduces women's distances more significantly than men's. Significant spatial clusters were found for women and men for work, leisure, accompanying trips and for studying. These clusters represent different types of destinations between men and women.

One of the principles of sustainable transport is to generate less travel. However, when this happens due to traditional gender roles, it draws attention, at least, to the need of creating transport systems that support women's daily activities more efficiently, to create a favorable scenario to surpass their spatial constriction. Therefore, it should not be forgotten that one of the three pillars of sustainable mobility is achieving social justice and equity (Hanson, 2010), aligned with the framework of transport justice, which is increasingly discussed in planning and research. Transport justice is seen as a political ideal primarily concerned with distributional equality of burdens, risks, access, or valuation of assets between different population groups, meaning distinct economic statuses, racial or gender identities, etc. (Gössling, 2016; Lucas, 2012; Martens, 2013; Mullen et al., 2014). In this context, this work has demonstrated an uneven distribution of burdens and access in gender inclusivity terms, not only considering gender, but also by economic status. By shedding light on the differentiated patterns between men and women, we contributed to providing gender-based evidence for developing more equitable mobility systems. For example, in terms of policy,

developing walking and cycling networks that connect residential areas to schools, shopping districts and health services that allow people to walk or bike for short utilitarian trips can be beneficial, as the convenience and availability of destinations close to home can encourage women to take up active transport (Yuan et al., 2023). Additionally, transit systems can be broadened or densified within residential neighbourhoods, to support women's suburban trips. Along this line, public systems can focus on an array of flexible alternatives in suburban areas, together with a diversification of land uses in these spaces. Also, it is necessary to broaden research on how variables as gender and ethnicity shape mobilities in less obvious ways than those related to access to resources, or opportunities (Steinbach et al., 2011), and that this contribution has only started to explore. This work analyzed the case of Montréal, but as human-centred transport policies are highly context-dependent, a strong starting point for policy would be to run these types of analyses for each administrative unit (city, town, joint councils, etc.) to understand its local reality related to gender for policy-making.

Limitations were identified during the development of this research, among them the dataset, which does not include disaggregated or detailed information about the family (parents, children, grandparents, or other caregivers present in the household, income differences between members of the household, etc.). This lack of fine details hinders more comprehensive analyses on the intersectionalities that produce dissimilarities in travel patterns between men and women, for example the interactions of race-gender-class and other variables. It is worth mentioning that the data as it is presented only contemplates the binary man/woman categorization, hiding the existence, patterns and realities of transgender and non-cisgender identities. Also, the dataset has information about destinations, but not about routes, which could also help enhance urban design and public policies to close mobility gaps between genders from an equity perspective. Furthermore, for anonymity and data protection, origins and destinations are geo-located on a grid of 250 m, which might reduce the spatial precision of the analyses. Nonetheless, this study has contributed to highlighting different clusters for destinations for men and women, which should support informed transport and land use planning for equity.

Future research can focus on the characteristics in terms of land use and transport systems of the different destinations of men and women, to try to elucidate what causes or support these differences and inform the development of more equitable transport systems. Other studies can also focus on the routes travelled by men and women, to gather evidence to enhance route planning and

design. Also, more efforts are warranted to explore novel data collection and methodological approaches to enable deeper gender-based analyses of spatial travel patterns. Finally, while some research has been done on the travel patterns themselves, the causes of power dynamics and intricate processes of negotiation and conflict have not yet been addressed.

CHAPTER 6: ARTICLE 3: HUMAN-CENTRED MOBILITY FLOW CLASSIFICATION: DIFFERENCES IN TRAVEL PATTERNS BETWEEN MEN AND WOMEN

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6.1 Introduction

Research and practice in transportation have long neglected important social dimensions of mobility. In particular, equity and justice considerations have typically been marginalized, which has spurred the field of *mobility justice* to interrogate inequities stemming from existing transportation planning paradigms (Sheller, 2018; Verlinghieri & Schwanen, 2020). Of particular interest to this field is how transportation systems and mobility landscapes are experienced differently across population segments. Yet, transportation research has commonly treated gender simply as an independent variable, though evidence suggests that gender significantly affects travel experience, and, therefore, that people have different transport needs related to their gender. Accordingly, a call has been made to better attend to the gendered dimension of mobility (Guerrero Balarezo et al., 2024; Hanson, 2010; Sánchez de Madariaga, 2013).

Transportation research often works with origin-destination (OD) data, which describes the endpoints of trips. OD data can be examined through its "flows", meaning spatio-temporal patterns of trips, to reveal characteristic features of travel behaviour. However, with large datasets containing thousands of flows, it can be challenging to discern meaningful travel patterns. To address this, clustering techniques have been used in flow analysis to identify patterns, even with very large trip datasets, and provide novel insights into a population's mobility (F. Liu et al., 2021). Quantitative analyses in transportation research and planning often neglect the gendered dimension of travel, sometimes due to the data itself, which may lack socio-demographic information (such as gender). This is especially the case with many sources of "big data", such as mobility platform

trips (e.g., bike-sharing) or cellular network movement data. However, data from OD surveys typically includes socio-demographic information, facilitating analyses of gender differences in travel.

This study examines a household travel survey in Montréal, Canada. Using a flow and clustering approach, we analyze the gendered dimension of mobility from the data across population segments. With this, we propose a method to address two research questions:

- RQ1: What differences exist in the patterns of urban mobility flows between men and women (with Montréal as a case study)?
- RQ2: How might socio-demographic or built environment factors explain these patterns for men and for women?

In what follows, we review related literature, present our methodology, subsequent results, and discuss possible next steps for this line of research.

6.2 Background

6.2.1 Flows and Clustering with Transportation Data

Flows are one of the fundamental cartographic data representations (Tobler, 1987), representing a movement between an OD pair. Flow analysis has a long history in movement analysis (Curry, 1972), with utility both in analytical research and as an intuitive form of data visualization (Dodge & Noi, 2021). Flows can be defined through Euclidean distance, representing an OD pair's shortest path (Golden & Ball, 1978), or can involve more complex movement through time and space, such as following a city's street network throughout the day (X. Luo et al., 2019).

In geography and urban planning research, flows are commonly used to analyze people's travel patterns. Liu et al. (2010) conducted a flow analysis to classify taxi trips' patterns and behaviours, demonstrating the use of a large dataset for understanding a type of mobility, while Guo et al. (2023) also used a taxi trip data with a trend surface model to examine spatio-temporal changes in travel patterns, identifying popular pairs of flows as deviations from the surface.

Travel data are collected from various sources, with varying information gathered. Travel data collected from shared mobility platforms typically lacks user characteristics (e.g., scooter-share and bike-share systems, see McKenzie (2019)). In contrast, OD surveys, which ask respondents about the origin and destination of trips, can collect trip characteristic (trip mode, purpose, etc.)

and socio-demographic information (e.g., Manaugh et al., (2010)). OD surveys, valuable sources of mobility flow data, are deployed by hundreds of cities worldwide, providing a valuable resource for understanding mobility patterns (Weiner, 2008).

A significant challenge for researchers working with flows is recognizing patterns in large volumes of data (Adrienko & Adrienko, 2011). One approach utilizes travel samples to manage the volume of the data (Bahbouh & Morency, 2014; Doantam Phan et al., 2005), while another synthesizes these trips into corridors. For example, Bahbouh (2017) aggregated groups of 10 trips between grid cells of 2,000 m in width to identify travel corridors, based on the collective demand of travel, its directions, and its paths. Another approach is cluster analysis, a statistical method used in geography to identify and classify similar geographic features or locations (Grubesic & Murray, 2001). This technique is widely used in geographic research to analyze spatial patterns and relationships among geographic entities such as regions, neighbourhoods, or environmental features (e.g., Decouvelaere et al., 2024).

Overall, research on OD flow clustering and pattern identification falls into two categories (Song et al., 2019). The first, focused on OD flow attributes including distance, volume, speed, and direction. The second, focused on the spatial distribution of flows in space, including methods using spatial statistics, hierarchical clustering, and density-based clustering. More sophisticated algorithms include hierarchical clustering, which creates a hierarchy of clusters by recursively merging or splitting clusters based on their similarity (Nielsen, 2016), and k-means clustering, in which data points are grouped into a predefined number of clusters (k) based on their similarity to the centroid of each cluster (Y. Zheng et al., 2015).

Clustering be useful for working with flows; for example, Zhu and Guo (2014) used a clustering method to identify flows similar to one another from a large dataset and extract travel patterns. Flows can also be used to delineate regions with similar or clustered patterns. Another method to group spatial flows is community detection (CD) (Comber et al., 2012): identifying clusters of interacting vertices (nodes or flows) in a network based on their properties (Javed et al., 2018; Kelley et al., 2012; Yang et al., 2013). CD methods partition the network into internally dense sub-networks with relatively weak connections to other network parts (Newman, 2004), letting researchers identify connected groups of nodes or edges, identify central nodes, and discover important shared connections (Ahajjam et al., 2018). Communities can be classified into two types:

disjoint communities, where nodes belong to a single community, and overlapping communities, where nodes connect to multiple communities (Fortunato & Hric, 2016).

While much of the community detection research lies in other disciplines, these methods have also been adapted for use in the social sciences. In urban studies, CD has been used to measure the degree of polycentrism in cities (Zhong et al., 2014), or to analyze mobility patterns within urban networks (Pappalardo et al., 2019). Based on CD algorithms, Bi et al. (2021) analyzed taxi passengers' travel hot spots using community detection on trip data. They found that the communities detected varied depending on the trip time of day, and that these exhibited spatial patterning, concentrated in central areas but scattered in outer areas.

A geographically weighted CD method was developed by Sekulić et al. (2021), to derive communities (regions) from flows while considering geographical similarity between regions. As geographical context is commonly omitted from CD analyses, the authors offer that this method will better capture local patterns and processes in region definition. They characterize flows and calculate their similarity to one another, based on location, length (distance), and number of travellers, and then use this computed similarity to detect communities. Based on the morphological and geometric characteristics of communities, they continue to classify them into two types: movement-based and place-based flow communities. The former refers to directed movement connecting different locations, while the latter implies scattered movement within an area. An acknowledged limitation of their work is that it does not account for the flow directionality, nor temporality, and also does not consider additional characteristics of movement, such as demographic and socio-economic information.

6.2.2 Gender in Transport

Since the late 1970s, scholars have found that women's mobility patterns differs from those of men (Giuliano, 1979; Rosenbloom, 1978b). Subsequently, Rosenbloom and Burns (1993) note that women's travel patterns diverge partly due to their household and child care roles, and norms regarding appropriate travel behaviour. For example, some women may avoid cycling due to social norms (Ravensbergen, Buliung, & Laliberté, 2020). The purpose of women's travel is more likely to be for household activities, both for themselves and for others under their care, largely affected by the need to access education, healthcare, and shopping facilities, especially in urban areas (Turner, 1984).

Some authors suggest that women's movements are often more complex than men's, possibly because women still bear most of the burden of household care, necessitating more trips, and chained trips (Kwan, 1999b). Researchers analyzing aggregate travel data and travel diaries for several high-income countries consistently report significant gender differences in trip purpose, distance, transport mode, urban travel patterns, and other aspects of travel behaviour (Cubells et al., 2020b; Elias et al., 2015; Olivieri & Fageda, 2021; Ta et al., 2022). Despite the growing recognition of the importance of gender considerations in transportation, and the robustness of current findings, many underexplored aspects of gendered travel remain, limiting our understanding of gendered aspects of urban mobility and our capacity to design policies promoting gender equality (Gauvin et al., 2020).

Geospatial analysis is an increasingly popular approach to interrogate the intersection between gender and mobility (Ozdenerol, 2021). One study analyzes urban mobility from a gender perspective using mobile phone records, census data, transit data, and points of interest data in Santiago, Chile (Gauvin et al., 2020). The analysis reveals a gender gap in mobility, with women visiting fewer unique locations than men, and by mapping this mobility gap, the authors found a wider gender gap associated with lower-income residents and limited accessibility to public transport. Kim et al. (2012) used commuting data to investigate job access in Hamilton County, Ohio, finding differences in commuting patterns between genders and occupations, and conclude that incorporating socio-economic data in flow analysis can reveal differences in results and their interpretations across demographics. McKenzie et al. (2025) analyzed geolocated fitness app data and found that running patterns vary between genders, including that women’s route selection was heavily influenced by time of day. These findings emphasize the potential of analyzing travel flows using clustering methods, to investigate the gendered dimension of mobility.

6.3 Methodology

We designed a three-step methodology to respond to the research questions (**Figure 6.1**). First, we applied a spatially aware community detection algorithm to classify flows with similar characteristics. Second, we classified the obtained communities into movement types according to their geometric characteristics, and examined these movement types through descriptive statistics. These two first steps address RQ1 (gendered differences in urban mobility flows). Third, to answer RQ2 (possible effects of socio-demographic and built environment factors), we generated

regression models to identify factors that may explain the movement types for men and women. These steps are detailed in what follows.

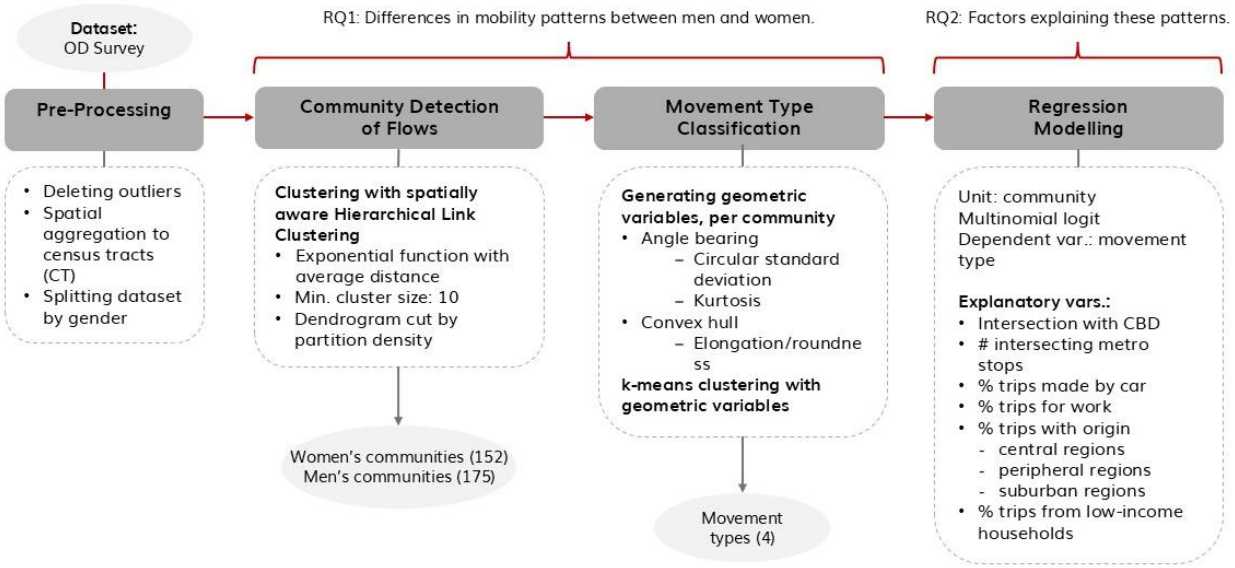

Figure 6.1. Methodology process to classify flows and movement types based on gender.

6.3.1 Case Study and Data

The metropolitan region of Montréal, Canada is used as a case study (**Figure 6.2**). The metropolitan area (~4.3 million inhabitants) comprises three urban areas: the island of Montréal, the municipalities of Laval (north-west shore of the river), and Longueuil (east shore); as well as two regions called "Crowns", with a more suburban-to-rural character. The three urban areas functionally interact for work and services, with the island being the most populated (~47% of the total metropolitan population (Ville de Montréal, 2021)). The Crowns are excluded from this analysis to focus on the central urban and suburban regions. Montréal island is divided in two central areas, the CBD (central business district) and the Centre (a vibrant area adjacent to the CBD), and two other areas, East and West, which still have some mixed residential and commercial land uses, but less so than the central areas. These areas will be referred to as *suburban on-island* for the reminder of this paper. This zoning corresponds to administrative regions defined by the ARTM.

In terms of travel characteristics, in the morning peak, 79% of trips are made for work and studies, and the dominant mode is the car (63%), followed by public transport (17%) (ARTM, 2018). Being an island, movement is highly conditioned by the water, with few crossing points between the

main island and neighbouring Laval and Longueuil (*suburban off-island* regions). In terms of connectivity to the central areas, the East and West regions are not affected by the barrier of the water, but they are not well-served by the metro network, whereas the metro does reach Laval and Longueuil.

Movement flows are obtained from the Montréal OD household survey of 2018 conducted by the *Autorité Régionale de Transport Métropolitain* (ARTM). The survey samples about 5% of the metropolitan region's population to record their travel diaries during one non-holiday weekday in the fall. The survey collects household information, personal information, and one-day trip information.

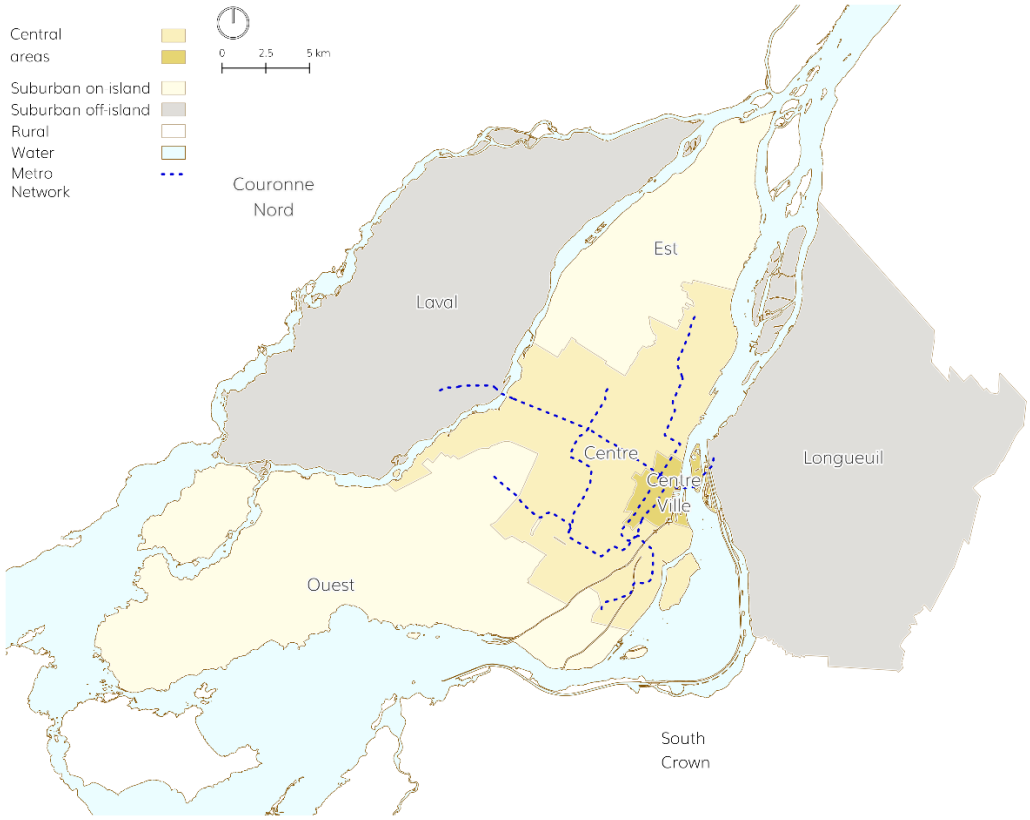

Figure 6.2 Study area Montréal, Canada.

6.3.2 Data Processing

First, to clean the data, we exclude trips returning home, trips made by people under 18 years of age, and trips shorter than 300 m. Trips returning home are excluded to avoid duplicated trips, while underage respondents are excluded to consider only trips of those with full autonomy in their

movement decisions, and very short trips are left out because they are close in length to the spatial unit of anonymization of the dataset (a 250 m grid). Additionally, trips with the longest 5% of distances (~18–56 km) are excluded to avoid outliers. For this analysis, we use the data without the expansion factor attached to the ARTM dataset, meaning that the results refer to the sample.

The OD survey provides origins and destinations points that are geolocated on a 250 m grid. We aggregate these points, separately for each gender, to the Census Tract (CT) to which they belong, to obtain enough aggregation of data for classification. We also tested another approach, with the centroids of the 250 m grid as the spatial unit, but a large portion of flows at this scale were single flows, and therefore less conducive for grouping into communities. Each pair of CTs with trips between them is then assigned the total number of trips that travelled between the pair, by gender, and the average of the distances between all OD pairs is assigned to its corresponding CT pair as a key characteristic. Hence, each CT pair is a unique element. This process produces a total of 40,491 flows (CT pairs), including both men and women, with the highest number of trips in a CT pair being 50, and the minimum being 1.

6.3.3 Community Detection for Men's and Women's Travel Flows

As with the previous step, the data is first split by gender to find distinct patterns of men's and women's travel. Then, we apply the methodology developed in Sekulić et al. (2021) to each gender's flows. This is a geographically weighted community detection method that captures the spatial nature of flows, generating compact communities that can help distinguish between different types of movement (movement-based or place-based in the original paper). The method proposes classifying edges (links), instead of nodes, according to their similarity, arguing that classifying edges allows for using both topological (network-related) and spatial information to identify clusters of interconnected movement flows with similar travel lengths and directions. The method is summarized as such:

- Assigning geographical weights: The geographical weight combines the magnitude of flows with a distance function. For this case, the magnitude of the flow is defined as the number of trips between the CT pairs. The distance function is defined as an exponential function that considers the ratio between the length of a given flow and the average length of all flows, to find communities around the average trip length in the city. The geographical weight follows the equation:

Equation 6.1:

$$GW_{ij} = w_{ij} * exp\left(-\frac{1}{\underline{d}} * d_{ij}\right)$$

Where the geographical weight is GW, d_{ij} is the length of a flow between the endpoints of a CT pair i and j, $\underline{d}$ is the mean length of flows in the network, and w is the magnitude of the flow (number of trips between that pair of CTs).

- Calculating similarity coefficients: With the geographical weights from the previous step, a similarity score for each edge is created using the Tanimoto coefficient (a generalization from the Jaccard index) (Tanimoto, 1958), where for each node *i* a vector is defined as an array that contains the weights of flows from node *i* to all the other nodes in the network. That vector is later compared to the corresponding vector of another flow to obtain the similarity coefficient.
- Creating a similarity matrix for all flows with the similarity coefficients.
- Identifying communities: The HLC (Hierarchical Link Clustering) algorithm (Javed et al., 2018) is used with the similarity matrix to merge flows according to similarity. This process generates a dendrogram with the hierarchical structure of the network. To find communities, the dendrogram needs to be cut at a given level. The cutting level of the dendrogram is defined by the partition density (Ahn et al., 2010), where resulting communities are separated by being most connected within each group, and least connected between groups.

6.3.4 Characterizing Movement Types

Following the community detection process, Sekulić et al. (2021) propose classifying them as either movement-based or local-based, based on their geometric characteristics: namely, with the relationship between the standard circular deviation of the angles of a community's flows, and their angular kurtosis. We add an additional characteristic of the roundness of the convex hull that contains the community, to capture other geographical aspects of movement types that are not captured by angular relations (circular standard deviation and kurtosis of the angles of the flows inside a community). The hypothesis for the inclusion of shape is that women tend to move in more round shapes, while men tend to move in more elongated ones. This hypothesis responds to the literature, which indicates that women make more short trips and perform more trip chaining,

while men tend to travel longer distances and for a single purpose (Ng & Acker, 2018). The roundness measure is calculated using the Polsby–Popper score (Polsby & Popper, 1991), described in the following equation, where values closer to 1 are more round, and values closer to 0 are more elongated:

Equation 6.2:

$$Roundness = \left(\frac{area}{perimeter^2}\right) * 4\pi$$

Using the three indicators of standard deviation, kurtosis of angles, and roundness, a classification is made using k-means (MacQueen, 1967) to find communities with similar types of movement. After calculating these three indicators for each community, they are transformed to z-scores, as the method is sensitive to units in different scales. Since the method can be sensitive to outliers, we identified outliers using a scatterplot and found them to be communities with over 700 flows. These were omitted, given that they cover the whole of the city and are therefore uninformative for the analysis. Using the scatterplot method, outliers are also found in communities with a kurtosis of the angles higher than 4 for women and 5 for men, which is reinforced by the criteria that when using z-scores, points under −3 or over +3 are considered to be outliers (Barnett Vic, 1994). The classification process is made separately for communities of men and women.

To further characterize the different categories, we conduct a descriptive analysis considering the number of intersecting metro stops per community (based on the convex hull) and whether a community of flows intersects the CBD. These two characteristics were selected because in Montréal, the public transport network is designed primarily around servicing the CBD, largely through the metro network. Outside the areas covered by the metro network, the public transport system relies substantially on bus coverage, but with a lower frequency and capacity, implying greater connectivity in areas covered by the metro. The two variables are calculated for each movement-type cluster, to describe how movement types, per gender, relate to the city and the provision of transport services.

6.3.5 Regressions

Then, we generate multinomial logistic regressions, with the dependent variable being the type of movement identified (categorical variable), to understand what factors might be associated with the different types. As independent variables, an array of possibly related factors are selected and

tested based on the literature regarding the differences in transport between genders and the knowledge of the case study area. These variables are aggregated to the community level, and communities are used as the unit of analysis. The variables considered are: the percentage of trips made by car, the percentage of trips made by public transport, the percentage of trips made for care purposes, the percentage of trips made for work purposes, as well as the percentage of trips with their origin in the central regions (CBD and Centre), the suburban on-island regions (East and West), and the suburban of island regions (Laval and Longueuil). Although all regions present some degree of mixture between residential and commercial uses, this simplification allows for splitting the city into relatively cohesive regions, based on land use, general patterns of mobility, and the boundaries formed by the water bodies. As for the personal characteristics of the individuals conducting the trips in each community, the variables considered are: the percentage of trips made by individuals in households with children, and the percentage of trips made by individuals from low-income households.

The models are generated separately for each gender, given that the cluster classification was made separately, and a step-wise approach is used. The variables of accessibility to work and care were tested, but were not kept in the final model because they were closely correlated to the percentage of trips made by car and the count of metro stations variables, and these other variables resulted in a higher log-likelihood (closer to 1). This process to obtain the most significant and informative models used a step-wise approach, where variables were dropped if they did not improve the McFadden score, and did not have a significant log-likelihood ratio when compared to the same model without the variable in question.

6.4 Results

6.4.1 Movement Types and Relation to the City

The community detection process clustered 72% of women's trips and 59% of the men's trips, resulting in 152 communities for women and 175 for men. Non-classified flows were not classified because of a lack of similarity to nearby flows, whether by location, length, or the number of travellers. The remaining 140 communities for women and 167 for men correspond to 51 % of women's flows and 50% of men's.

Following the k-means classification of the communities, four clusters are identified for both genders using the elbow method to select the optimal number of clusters (Thorndike, 1953). In

both cases, the elbow method exhibited a clear cut-off point. The four movement types are identified based on their geometric properties, as follows: *movement-based*, *local-based*, *mixed-round*, and *mixed-elongated.* **Figure 6.3a** presents the variation of the three variables (circular standard deviation, angular kurtosis and roundness/elongation) for the four movement types, by gender. Most intervals of each variable have a large overlap between genders, showing categories of relatively homogenous characteristics, despite being classified separately.

Figure 6.3b synthesizes the characteristics of the four movement types. *Movement-based communities* have a low standard deviation of angles with a high kurtosis, where flows are oriented in a more unidirectional fashion and there is no pattern of roundness or elongation. Conversely, *local-based communities* are characterized by a high standard deviation of angles and low kurtosis, encompassing more multidirectional flows, and tend to be more round. Communities with both the distribution of kurtosis and the standard deviation having low to medium values, are designated as *mixed*, implying a variation in the level of directionality of the flows, and then are separated by their roundness into *mixed-elongated* and *mixed-round*.

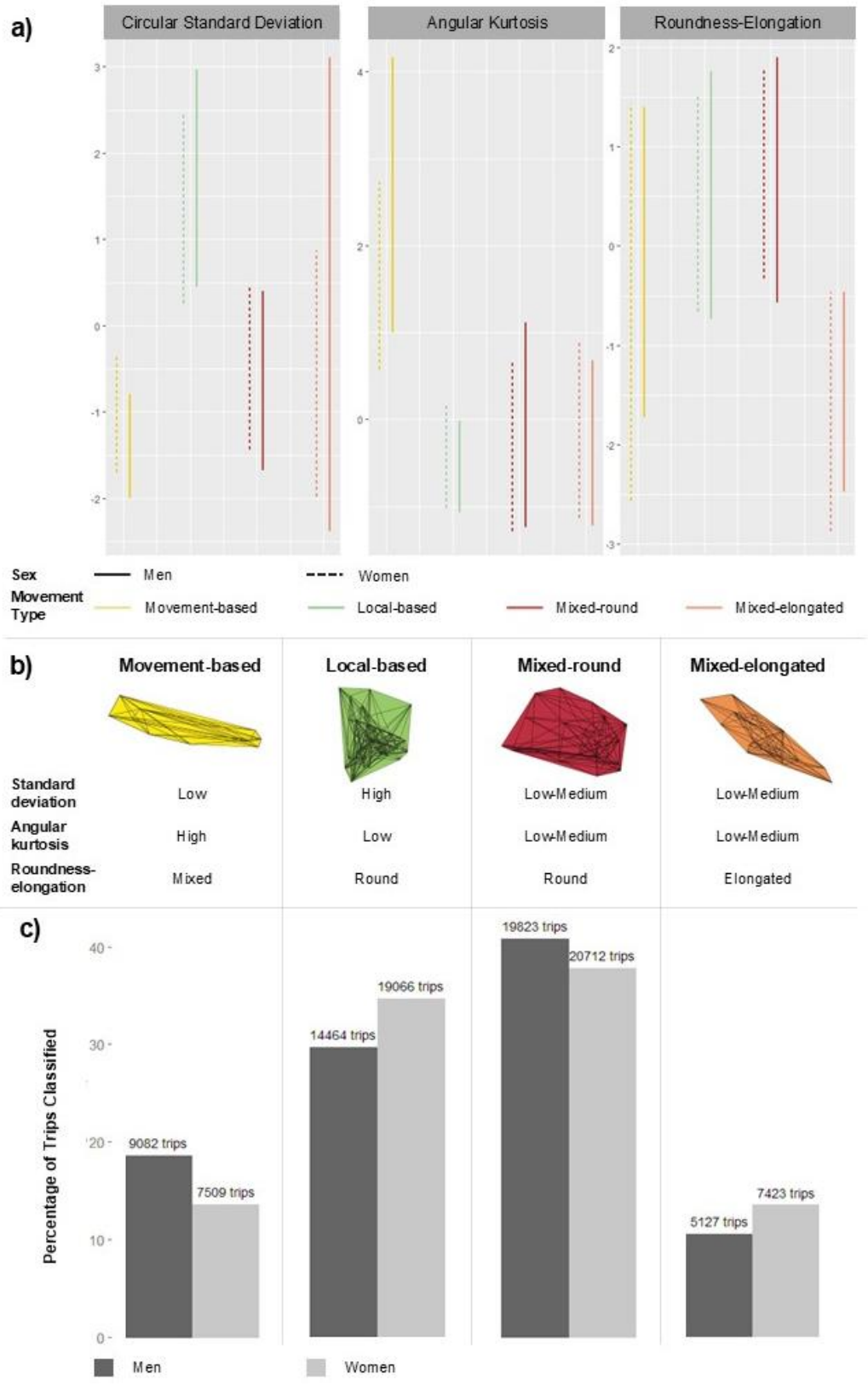

Figure 6.3 Movement type classification characteristics.

Figure **6.3c** shows local-based and mixed-round are the two most predominant movement types for both men and women. Interestingly, the local-based type includes a greater number of trips for women, while this is the opposite for the mixed-round type. Similarly, a larger number of women's flows are of the mixed-elongated type.

To assess statistical significance in the observed differences, we run two statistical tests. The first is a t-test for the mean for each type, which evaluates the absolute difference between the mean number of trips per community. The second is a Kolmogorov-Smirnov two-sided test, which assesses the difference in the distribution of the number of trips per community for each movement type. As shown in **Table 6.1**, the t-test results suggest that there are significantly more trips in the women's communities for the local-based (90% confidence interval (CI)), mixed-elongated (95% CI), and mixed-round (90% CI) types. While this could be due to an overall larger number of classified women's trips (as compared to men, see **Figure 6.4**), it is interesting to note that the movement-based type exhibits a higher mean for men than for women, although no statistical difference is observed. In other words, while the number of women's trips is typically higher for women than for men across the dataset, and for other types of movement, this is not the case for the movement-based type. Accounting for the difference in sample size, the results of Kolmogorov-Smirnov suggest that there are significant differences for the local-based (95% CI) and mixed-elongated types (90% CI). Overall, the results demonstrate that women's trips are overrepresented in both the local-based and mixed-elongated types.

Table 6.1: Statistical tests on the number of trips per movement type.

Movement Type	**Difference in means (t-test)**						**Distribution (Kolmogorov-Smirnov two sample test)**		
	t	*df*	*Mean Men*	*Mean Women*	*p*	*sig,*	*D*	*p*	*sig.*
Movement-based	0.31	47.930	349.31	312.88	0.756		0.250	0.346	
Local-based	-1.83	68.092	314.43	465.02	**0.071**	.	0.373	**0.003**	**
Mixed-round	-1.68	67.570	314.65	470.73	**0.097**	.	0.187	0.275	
Mixed-elongated	-2.57	48.766	160.22	239.45	**0.013**	*	0.394	**0.011**	*

Sig. Codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.'

Figure 6.4 presents the location and shapes of the communities per movement type, demonstrating a spatial difference between men and women in all categories. The movement-based communities of both genders tend to circle the central areas, but concentrate in different areas. For this category, the communities of women are absent from the East, while men's communities are absent from Longueuil. The local-based communities for both genders are more centrally located than the three other categories, especially for men. Men's communities are highly concentrated in and around the CBD, whereas women's communities are more concentrated in the Centre and through the island of Montréal. Similarly, the mixed-round movement type shows a difference in spatial concentration, where men's communities are more concentrated in the Centre and the East, whereas women's communities concentrate in Longueuil. As for the mixed-elongated category, the main difference between genders is that for women, this cluster is mainly concentrated on the East area (connecting it to the Centre), whereas for men, the communities in this category are more dispersed throughout the city (with most of them connecting with the CBD).

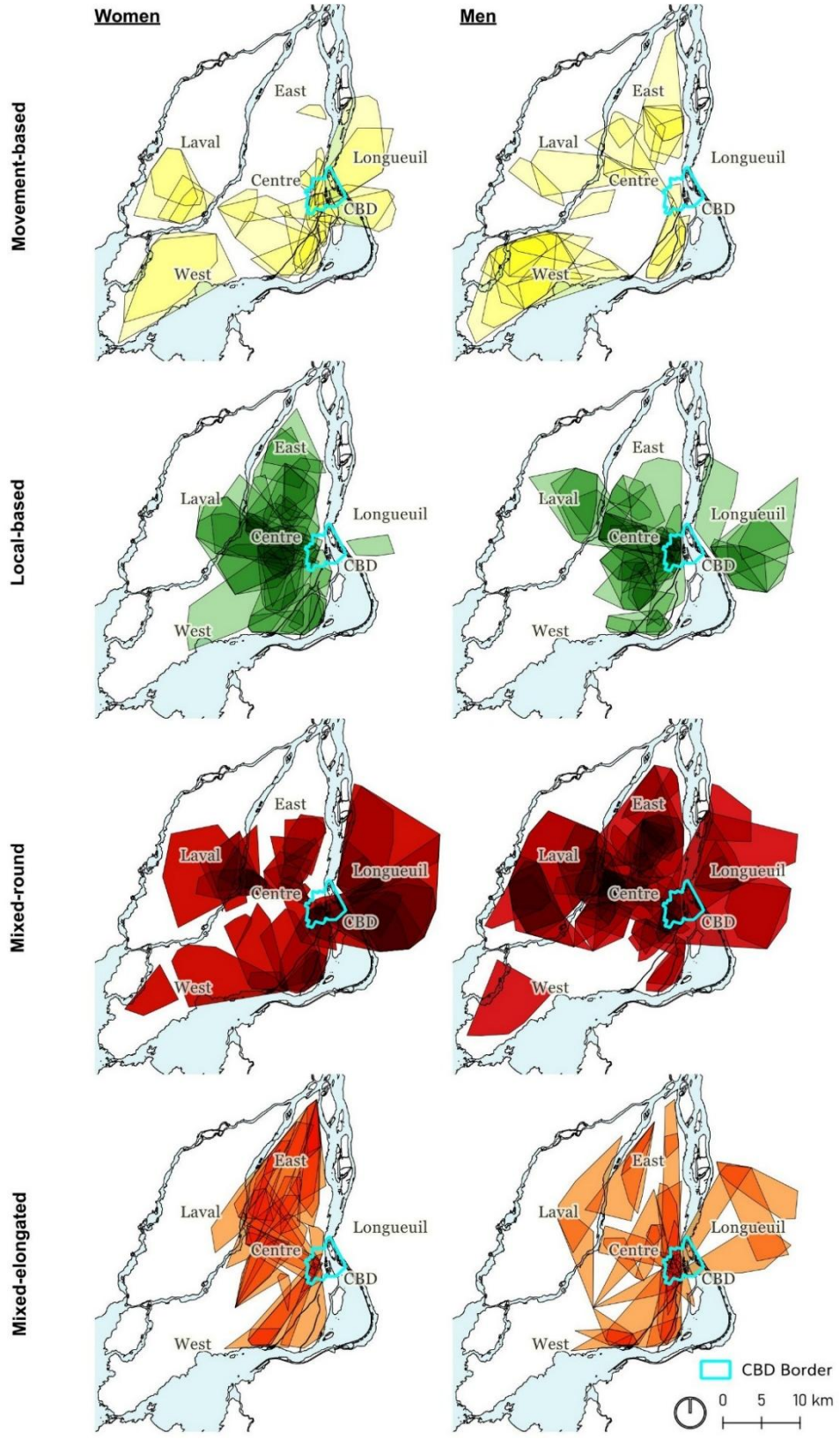

Figure 6.4 Map of movement types, per gender.

To further explore the relationship between the location of the movement types and the city, **Figure 6.5** presents the percentage of communities that intersect with the CBD, and the number of metro stops contained within each community, by gender. As for the relation with the CBD (**Figure 5a**), while the movement-based type tends to be suburban in nature, women have nearly 40% of communities intersecting with the CBD, while men only have around 13%. These results suggest that this type of community is more dominantly suburban for men than for women (see **Figure 6.4**). This also aligns with the results observed in **Figure 5b**, where movement-based communities tend to be located more centrally for women. As such, a larger proportion of communities with more than 30 metro stations is observed for women. Conversely, local-based communities are more suburban for women, where more than 75% of women's local-based communities do not intersect with the CBD, as compared to 65% for men. In terms of overlap with the metro system, women's local-based communities tend to be overrepresented in suburban areas (number of metro stations below 15), as well as in central areas outside the CBD (with a relatively high number of metro stations: above 30, but rarely above 60). The communities in the mixed-round category are predominantly outside the CBD for both genders, and a high share of communities have less than 20 metro stations. Finally, the mixed-elongated type exhibits large differences between genders, with around 50% of the communities of men intersecting the CBD, versus 33% for women. There is also a higher proportion of men's communities with a large overlap with metro stations, confirming the centrality of the mixed-elongated movement for men. These results are consistent with the maps in **Figure 6.4**.

Overall, mixed-elongated communities tend to be more strongly tied to the CBD for men than for women. Similarly, local-based communities appear to be more central for men, whereas for the movement-based type, women's communities are less suburban than men's and exhibit stronger connections with the CBD. Finally, for the local-based and mixed-round types, the main differences lie in distinct spatial concentrations.

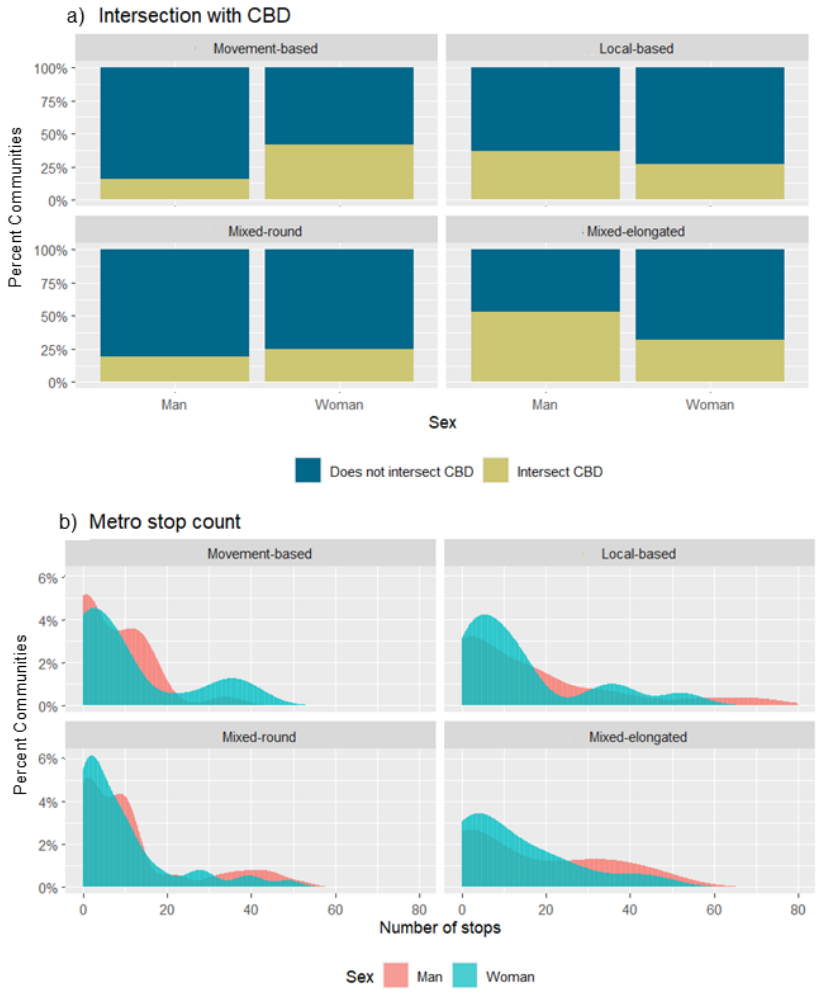

Figure 6.5 Relationship between movement types and intersection with the CBD and the metro network.

6.4.2 Regression Analyses: Examining Explanatory Factors

To further understand the nature of each movement type, regression analyses modelling the movement types are performed. **Table 6.2** presents the final models, with significant relationships highlighted in colour. Both models use the same variables to allow for comparing between genders. The movement category local-based is used as the reference category.

For the women's model, there are no significant relationships found between the percentage of trips made by car and the movement type. With respect to centrality, a higher number of metro stops is negatively and significantly associated with the mixed-round (95% CI) and movement-based (90% CI) types. In other words, when controlling for other variables, communities with a large overlap with the metro network are more likely to belong to the local-based category than to

the mixed-round and movement-based categories. Conversely, a higher percentage of trips starting in the suburban on-island regions is positively associated with the mixed-elongated type, implying that communities with a higher number of trips from the suburban on-island regions are more likely to be of the mixed-elongated movement type than of the local-based type, in line with the results shown in **Figure 5**. There is also a positive significant relationship with trips starting in the suburban off-island regions and the mixed-round and movement-based types, implying that women's trips from off island are more likely to be of these types, than the local-based type. As for the percentage of trips made for work, a higher percentage of work trips is positively related to all three movement types, implying that work trips are less often of the local-based type. In relation to the percentage of trips from low-income households, there is a positive association with the mixed-elongated type (90% CI), indicating that communities with a high number of trips made by individuals in low-income households are more likely to belong to the mixed-elongated category than to the local-based one. This is discussed further in the next section.

For the men's model, there is a positive and significant relationship between the percentage of trips made by car and the movement type, for both the mixed-round and movement-based types. This suggests that these movement types are more aligned with car trips than the local-based ones. Conversely, whereas the number of metro stops was significant in the women's model, there is no significant relation observed for men. As for the region of origin of the trips, the suburban on-island and suburban off-island coefficients are negative. This suggests that when men's trips have a non-central origin, the probability of a community to belong to the local-based type increases. These results also imply a more suburban nature for the local-based movement type. Regarding the percentage of trips made for work, for women, there is a positive and significant relation with the mixed-elongated and movement-based types, meaning that a community with a higher number of work trips would tend to belong to these types of movement. Finally, there are no significant relations with the percentage of low-income homes, in contrast with the results of the women's model.

Table 6.2: Regression models: effects of selected variables on movement types.

		WOMEN					**MEN**				
		Log-Lik.: -160.08		Base cat.: Local-based			Log-Lik.: -194.34		Base cat.: Local-based		
		McFadden R^2: 0.159					McFadden R^2: 0.124				
		Estimate	*Std. Error*	*z-value*	*Pr(>|z|)*	*sig*	*Estimate*	*Std. Error*	*z-value*	*Pr(>|z|)*	*sig*
Transport and land use characteristics											
Intercept	*Mixed-round*	-1.762	2.162	-0.815	0.415		-3.700	1.951	-1.897	0.058	.
	Mixed-elongated	-5.229	2.544	-2.056	0.040	*	-3.678	2.303	-1.597	0.110	
	Movement-based	-1.969	2.467	-0.798	0.425		-7.955	2.633	-3.021	0.003	**
% trips made by car	*Mixed-round*	-1.699	1.946	-0.873	0.383		6.546	2.210	2.963	0.003	**
	Mixed-elongated	-2.720	2.426	-1.121	0.262		-0.609	2.434	-0.250	0.802	
	Movement-based	-3.536	2.314	-1.528	0.126		8.448	3.051	2.769	0.006	**
Count of metro stops	*Mixed-round*	-0.640	0.286	-2.237	0.025	*	0.129	0.277	0.465	0.642	
	Mixed-elongated	0.144	0.325	0.444	0.657		-0.075	0.283	-0.266	0.790	
	Movement-based	-0.541	0.319	-1.698	0.090	.	-0.415	0.481	-0.862	0.389	
Suburban on-island region	*Mixed-round*	0.246	1.095	0.225	0.822		-2.754	1.240	-2.221	0.026	*
	Mixed-elongated	3.746	1.288	2.908	0.004	**	1.782	1.434	1.242	0.214	
	Movement-based	1.529	1.322	1.157	0.247		-2.084	1.466	-1.422	0.155	
Suburban off-island region	*Mixed-round*	2.395	1.130	2.119	0.034	*	-2.347	1.065	-2.204	0.028	*
	Mixed-elongated	-0.549	2.644	-0.207	0.836		0.615	1.325	0.464	0.642	
	Movement-based	3.349	1.350	2.480	0.013	*	-4.811	1.606	-2.995	0.003	**
Trip purpose and household income											
% trips made for work	*Mixed-round*	9.771	4.734	2.064	0.039	*	0.118	3.575	0.033	0.974	
	Mixed-elongated	10.440	5.316	1.964	0.050	*	8.496	4.072	2.086	0.037	*
	Movement-based	10.929	5.390	2.028	0.043	*	7.464	4.476	1.668	0.095	.
% trips by individuals in low-income households	*Mixed-round*	0.679	3.558	0.191	0.849		3.154	3.173	0.994	0.320	
	Mixed-elongated	7.291	4.144	1.759	0.079	.	2.743	3.672	0.747	0.455	
	Movement-based	0.504	4.031	0.125	0.901		4.061	3.738	1.086	0.277	

Sig. Codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.' Shading : significant variable Colour: orange (women), green (men).

6.5 Discussion

The results demonstrate that there are significant differences in the spatial patterns of men's and women's travel. There is a higher percentage of women's trips classified in the local-based movement type, a difference that is consistently significant across the different statistical analyses. This finding is in line with the idea that the pattern of women's travel is more spatially complex (Scheiner & Holz-Rau, 2017; Uteng, 2021; Y. Zhang & Song, 2024). The local-based movement type is characterized by multidirectionality (of the angles of the flows inside a community) and inter-borough movement (in the local case for women, connecting suburban on-island areas at the north of the island to the Centre) – indicative of the shorter, multi-purpose and complex trip chaining associated with women's trips (Ng & Acker, 2018).

Local-based communities are concentrated in the central and suburban on-island areas (whereas for men, they are concentrated mainly in the CBD). In Montréal, the metro network is integral to accessibility through public transport, and when reaching suburban on-island areas, the local connections to the public transport network are weakened. This would imply that women's most characteristic trips happen at the edge or outside of the core of transport connections structured by the metro, potentially making women's trips more difficult.

In contrast to our initial hypotheses that women would move more in the local and round types, there is also a higher percentage of women's trips in the mixed-elongated movement type as compared to men's trips. While this type of movement was initially thought to be more closely associated with the movement patterns of men, it is important to note that, in this study, the mixed-elongated movement of women is not strongly associated with the CBD, as is the case for men. Therefore, while this category seems to be capturing typical suburban-CBD commutes for men, it is not the case for women. It mostly captures long flows along unidirectional corridors, between suburban on-island and central areas (including but not limited to the CBD), and almost exclusively on the island. In Montréal, as an island, the water acts as a geographic barrier that highly conditions movement and land use development. In this study, we observe that it more strongly conditions the elongated movement of women, whereas men's flows cross the barrier from the off-island suburbs to the central areas. These findings suggest that, even in more elongated flows, women maintain a type of local movement (on-island versus metropolitan movement). As expected, work trips are associated with the mixed-elongated type (as compared to the local-type) for women. Both

findings, of on-island travel and the work nature of trips, indicate a movement pattern that accords to theory; that, even after controlling for socio-demographic differences, women may seek jobs that are less centrally located, as compared to men (Gutierrez, 2018; Hong & Lee, 2026).

The regressions indicate that while men and women can produce relatively similar categories of movement patterns, men's travel and women's travel respond to different factors, both geographically and in terms of trip characteristics. The regressions point towards a relationship between low-income and the mixed-elongated category for women, showing that women from low-income households, and specifically travelling on flows from central to suburban on-island areas, tend to make longer trips (characterized by the elongated-mixed type). Although previous research in Montréal found longer trips for women are related to middle- and high-incomes (Guerrero Balarezo et al., 2024), the spatial method in this paper has allowed for finding the nuance in this result. One plausible explanation for longer trips from the East region is due to the shape of the island, where travelling from the East westwards takes longer, and these corridors connect lower-income neighbourhoods with clusters of jobs for lower-income women. Around 50% of men's communities in the mixed-elongated type of movement intersect with the CBD. The results also suggest that men's clusters comprising more non-car flows and originating from central areas are more likely to be in mixed-elongated clusters, which aligns better with the public transport network in the case of men's communities; therefore, public transport infrastructure is possibly facilitating longer trips for men, more than it does for women. This indicates that the mixed-elongated movement of men are more directly aligned with the public transport system of the region, which is centralized around the CBD and caters to longer trips.

Overall, findings show that both local-based (typically shorter) and mixed-elongated (typically longer) flows are more present among women than men. This method is able to capture the nuance of the different types of movement associated with women's travel flows. Moreover, by considering the location of the patterns, this method allows for designing area-specific policies. For example, in this case, the method sheds light on the fact that the mixed-elongated movement type of women is concentrated along specific corridors (to the East), which could be prioritized in terms of public transport interventions.

Implications also follow in terms of gender-sensitive transport planning. The findings support the potential benefit of developing high-frequency (including off-peak) rapid bus corridors along

commercial streets outside the CBD, to support low-income populations (see Vermesch et al. (2021)), which would strengthen the currently weaker transport structure in Montréal outside of the metro area. Further, to support women's local-based movement, work can be done to strengthen intra- and inter-neighbourhood connections.

There were some limitations to this study. For identifying communities, the algorithm requires a large dataset; therefore, it was not possible to segment the data by mode, trip purpose, or time. This would offer interesting nuance to the differences between gender patterns, as there was too much data sparsity following that segmentation. Similarly, a census tract level of spatial aggregation limited the possibility of incorporating detailed land use analyses, which may have revealed interactions between travel patterns and urban development[4]. The study was limited by the data in considering only man or woman as gender categories, as in the OD survey, respondents can only mark their identity as either man or woman. Future research could also apply this method to other categorical divisions of travel in a similar manner (e.g., ethnicity, immigration status, income). Another limitation of the method was that some trips were not classified, with 72% of the trips of women and 59% of the trips of men classified. No similar flows were found surrounding the unclassified trips, whether because of their length or the number of trips made between the pair. Future research can also focus on this segmenting of the dissimilar trips, to understand their nature and role within the urban system.

Future research could use this method with other datasets to evaluate how the observed patterns vary across geographical context. The method was found to capture nuanced spatial and movement patterns, and is well-suited to a human-centred approach to transport analysis. This study demonstrates the importance of collecting detailed travel data, both in terms of spatial and demographic detail. In our analysis, the principal human factor considered was gender, and we demonstrated this method's ability to reveal spatial and geometric differences in gendered travel. Finally, the contribution of this paper lies mainly in the demonstration of the applicability of the methodology to reveal distinct spatial patters. However, more efforts are warranted to analyze the results in relation to the region's land use and transport characteristics.

[4] Trips under 300m, that are very characteristics of women's mobility patterns were also excluded from this study due to geographic anonymization conditions. This can obscure integral parts of women's movement; however, the method showed its capacity to find important gender differences.

6.6 Conclusions

This study analyzed the spatial differences in the movement flows of men and women using a community detection algorithm, and then classifying communities into types of movement. Types of movement were classified according to the angular relations between the flows inside a community and the shape of the convex hull that contains the flows, thereby capturing elongation as well as the directionality of the flows. Four movement types were identified: movement-based, local-based, mixed-round, and mixed-elongated. Regressions were then developed to identify different factors that can influence these patterns.

To answer our first research question, about differences in the patterns of the flows of men and women, we found that women's trips are observed in greater proportion in the local-based movement type, and that these types of movement are less centrally located for women than men. We also found that there is a significant difference in the movement characteristics between men and women in the mixed-elongated movement type: women's mixed-elongated communities have more long-distance trips across the island, whereas men's communities are more closely connected with the CBD. To answer our second research question about the factors that influence these patterns, we found that the classification of women's flows relates to public transport infrastructure, purpose of the trips, and socio-economic variables, while men's trips are not affected by socio-economic status or closeness to transport infrastructure.

Our study demonstrates the utility of this two-step spatial flow clustering method, which allowed us to find nuanced differences between the mobility patterns of men and women, and the interaction between these mobility patterns and income, centrality, public transport service, and trip characteristics. While existing research works with sex/gender differences in travel patterns, the clustering flow method facilitates a spatial approach for visualizing and characterizing mobility flows. Further, the inclusion of the shape variable to classify movement (elongation-roundness) proved useful in highlighting the nuanced differences in spatial patterns between men and women. By adopting a human-centred approach to flow analysis, we showcase how doing so can help investigate the interactions between spatial patterns and human factors of interest to research and policy.

CHAPTER 7: ARTICLE 4: EXPLORING THE RELATIONSHIP BETWEEN GENDER, TRAVEL DISSONANCE, AND ATTITUDES IN MONTRÉAL, CANADA.

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7.1 Introduction

How people travel, including the mode they use, does not always match their feelings about that mode. For instance, some people drive to work every day but dislike the experience, and would rather take public transport. This is referred to in the literature as travel mode dissonance: the mismatch between attitudes about particular travel modes (including mode preference) and travel mode choice (the mode actually used) (De Vos & Singleton, 2020b). Understanding the factors behind travel mode dissonance can help identify ways to support individuals in using their preferred mode, as dissonant travellers may be more likely to change their travel behaviour than consonant travellers (McCarthy et al., 2023). Specifically for dissonant car users, who would prefer to use public transport or active modes, investigating dissonance may help in identifying factors where intervening can lead to lower car dependency, while at the same time increasing travel satisfaction.

In terms of general travel behaviour, women (compared to men) are more prone to chain together trips, travel at off-peak times, and make shorter trips, often with the purpose of caring for others – behaviours that often are not properly accommodated for in traditional public transport service planning, oriented toward supporting commuting travel (Babbar et al., 2022). This structure is likely to result in a mismatch between women's needs and transport systems, suggesting that travel mode dissonance may be experienced differently across genders. Hence, supporting the design of gender-aware policies derived from understanding dissonance can ensure that strategies implemented to reduce car dependency also support gender equity in transport.

While recent research on dissonance and gender revealed important differences (Alfaro et al., 2025; Hu et al., 2023; Pani et al., 2023), the topic remains largely unexplored. Only a few studies have

examined dissonance from a gender perspective. These studies were conducted in different contexts (e.g., Spain, China, and India) and from a different standpoint (e.g., with a focus on travel satisfaction, public transport usage intention, or multimodality). Therefore, this body of research leaves large areas underexplored and central gaps remain. A first gap is the lack of research focusing on car dependency, to support a sustainable mode shift that considers the specific realities of men and women. A second gap is the scarcity of gender-focused studies on travel mode dissonance in North America, particularly in Canada. Since studies on travel mode dissonance have found contrasting results across contexts (De Vos, 2018; Mella-Lira & Paez, 2021; Negm et al., 2024), this points to the need for context-specific studies to understand how men and women react differently to their local transport system.

This study thereby investigates the difference in travel dissonance between genders, focusing on attitudes towards different transport modes among car users. Using a large-scale mobility and attitudes survey conducted in Montréal, Canada, we first present a descriptive analysis of travel dissonance type between genders. An in-depth analysis of travel attitudes (criteria individuals value when choosing a mode) and perceptions about modes (adjectives used to describe the different modes) is then performed across mode dissonance type and gender. Lastly, we develop two multinomial logit models (one for women and one for men) to assess the influence of socio-economic variables and travel attitudes on travel dissonance type, and how these relationships vary by gender. This study enriches the literature on travel mode dissonance and gender, offering insights that can support researchers and planners in identifying effective strategies to reduce car dependency among both women and men.

7.2 Literature Review

The study of travel dissonance adapts cognitive dissonance theory from social psychology (Festinger, 1957) as a framework to understand the relationship between travel behaviours, attitudes, and satisfaction. Cognitive dissonance is an individual's mismatch or inconsistency between attitudes and behaviours regarding a topic, which produces discomfort, frustration, and dissatisfaction, that eventually forces the individual to either change their behaviour, or change their attitudes in the case that a behavioural change is not possible (De Vos & Singleton, 2020b). De Vos and Singleton (2020b) use this approach to study the dynamics between travel-related attitudes and behaviours. Specifically, they investigate the relationship between travel mode

choices and residential location choices, and related satisfaction with travel and residential location. Recent studies have adopted this framework to study: the travel satisfaction of captive users, meaning those that are effectively unable to choose their mode (Guan & Wang, 2024); the incompatibilities between attitudes of multimodal users, such as those who dislike a particular mode but are forced to use it for part of their travel (An et al., 2022); and, the assessment of travel satisfaction through the concept of ideal travel time (Ma et al., 2021). All these studies have strong policy implications, through the exploration of particular aspects of transport systems that can be addressed to lead to higher travel satisfaction and less dissonance.

In the study of the relationship between travel mode dissonance and travel behaviour, recent research highlights key differences in dissonance and satisfaction based on the mode used to travel (De Vos, 2018). Overall, in studies in high- and low-income countries, public transport seems to be the mode with which more users feel dissatisfied and experience dissonance (De Vos, 2018; Mella-Lira & Paez, 2021). Conversely, Negm et al. (2024) found, in Montréal, Canada, that dissonant car users have the lowest probability of satisfaction. Another study in Portland, U.S. also found that car users are the most captive (Humagain et al., 2021). Consistent across all contexts, the use of active modes seems to produce more satisfaction (De Vos, 2018; Mella-Lira & Paez, 2021; Negm et al., 2024), and are the modes that are most chosen discretionarily (Humagain et al., 2021). Complementarily, Mella-Lira and Paez (2021) find that for dissonant travellers in Santiago, Chile, active travel is the mode most associated with freedom, enjoyment, and happiness, and public transportation is most associated with a feeling of poverty.

A few studies have specifically investigated travel dissonance from a gender lens, identifying significant differences in terms of attitudes, satisfaction, and dissonance. Previous research on gender and travel dissonance indicates that, among car users, more women were car consonant (travel by car and are satisfied): studies in Ganyu, China (Hu et al., 2023) and Delhi, India (Pani et al., 2023) have found this same trend. Pani et al. (2023) also found that the mode where users experience the most dissonance is public transport, but women to a lesser extent than men. Another study in Germany found that women were more likely than men to experience trips made for household care purposes as unpleasant (Chidambaram & Scheiner, 2025).

Research has also highlighted that there are factors that affect genders differently in relation to dissonance. Women travellers were more likely to identify travel safety as a problem in public

transport than dissonant men (Pani et al., 2023). Another study conducted by Beirão & Cabral (2008), in the Porto region of Portugal, found that women had a higher sensitivity to travel stress and cost, a greater desire to change modes, and less of a desire to signal social status. In contrast, they identified that men exhibited a greater need for control, and expressed more positive attitudes toward public transportation. Other studies in Nagoya, Japan (Gao et al., 2024) and Vienna, Austria (Janke, 2021) assessed gender differences in residential dissonance related to travel satisfaction, also finding gendered patterns.

In the relationship between travel dissonance and gender, although the body of literature is scarce and fragmented, findings suggest that geographical context matters, as does culture, geographical conditions (like street connectivity, slope, water courses, etc.), distance, and the availability of modes, all of which relate to people's attitudes toward travel modes (Hu et al., 2023). Notably, there were no gender-specific studies about travel dissonance and attitudes in North America, and relatively few world-wide. Additionally, understanding the reasons individuals might have to switch from the car to active and public transport, and how this varies between genders, is useful in generating targeted policies to support sustainable and equitable mobility. Therefore, a gender disaggregated study about travel dissonance in Montréal fills a gap in the literature around this specific context.

7.3 Methodology

7.3.1 Study Area and Data

This analysis focuses on the Montréal metropolitan region (4,760 km2), Canada, an urban area of 4.3 million inhabitants (Government of Canada, 2022), composed of the island of Montréal and the suburban off-island areas of Laval and Longueuil, as well as two exterior, more rural, surrounding zones ("couronnes") (**Figure 7.1**). The island of Montréal has the downtown and central areas, and two sectors of a more residential nature to the extreme north and south of the island. The island of Montréal is the economic centre of the region, though Laval and Longueuil still have large industrial and employment areas. These eight territorial divisions correspond to regions defined by the regional public transport authority, the Autorité Régionale de Transport Métropolitain (ARTM). Montréal's transport system has four metro (subway) lines, one light rail (not in service at the moment of the data collection and, therefore, not shown on the map), a suburban commuter train service, an extensive bus network, and a paratransit service. The modal

share across the Montréal metropolitan region is split 67% car, 13% public transport, 16% active transport, and 4% other modes (ARTM, 2023a). Women are 54% of public transport users and 49% of car users (ARTM, 2023a).

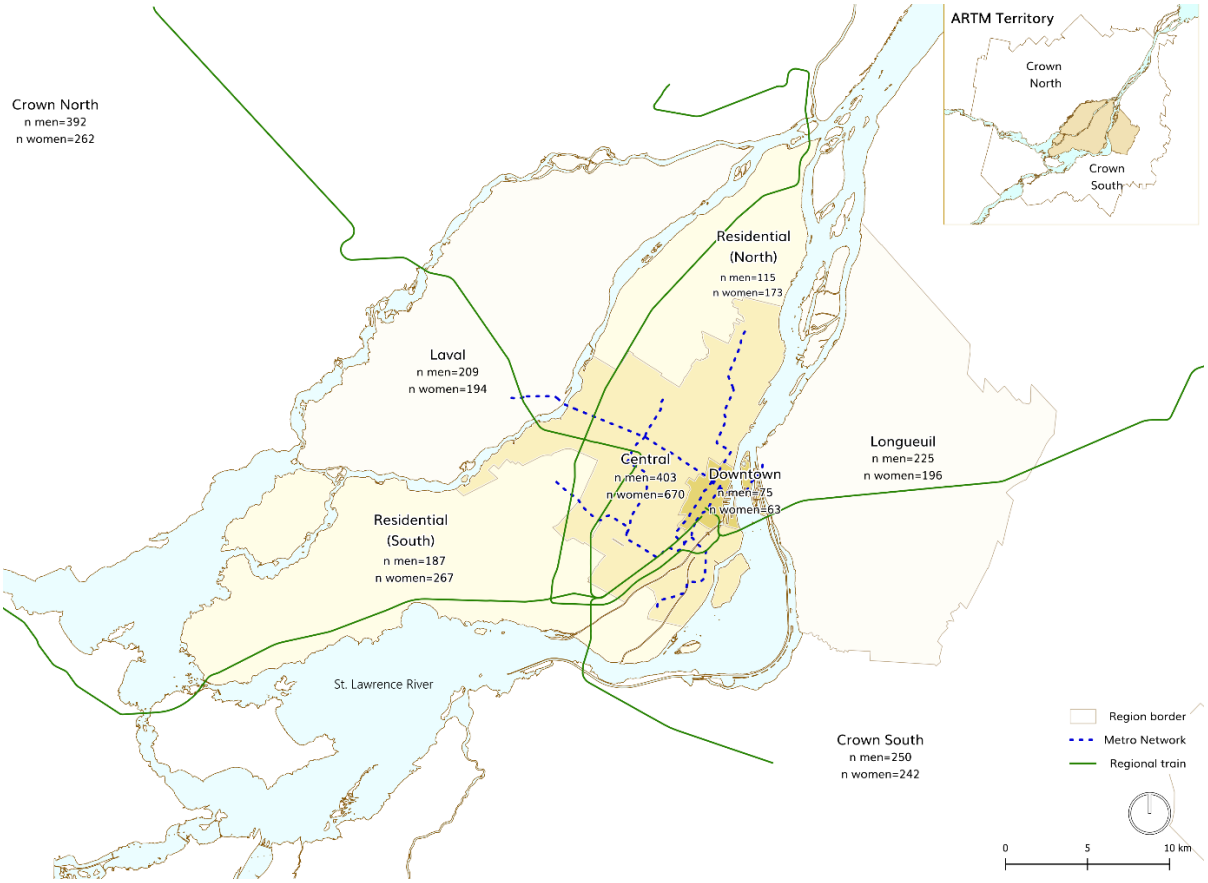

Figure 7.1. Map of the study area showing 6 ARTM (Autorité Régionale de Transport Métropolitain) regions around the island of Montreal, and the metro and rail networks. Inset map shows the total ARTM region, including two additional outlying “Couronnes” regions. Numbers represent the sample population from reach region.

To understand the relationships between travel dissonance, attitudes, and gender, we used the 2023 Mobility Segmentation Study Survey conducted by the ARTM (Autorité Régionale de Transport Métropolitain, 2023). The survey was originally carried out for the marketing team to identify population segments with distinct transport needs that could be targeted by the agency for interventions. Data was collected online on November 2023 through an external web platform and the internal ARTM platform. The survey targeted residents of ARTM’s territory aged 18+. Originally, the database contained 4,057 observations. Minority gender categories were excluded

because of insufficient observations for statistical tests, leaving 3,891 observations (1833 men and 2058 women, in all transport modes).

The database contains three categories of variables: travel behaviour; attitudes and perceptions about travel modes; and personal characteristics, such as gender, income, education level, ethnicity, etc. **Table 7.1** contains a summary of the structure of the dataset. The travel behaviour section contains questions about travel frequencies per mode, travel time of day, subscriptions to car and bikeshare services, etc. The attitudes-perception section has two main subsections that were used in this analysis: one where users rate (from 1 to 10) the importance of 24 criteria in their decision to choose a particular mode, and another allowing users to select adjectives they associate with each mode, from a list of 66 possible adjectives. Importantly, the questionnaire includes questions about travel mode currently used, and preferred mode, which allows for assessing travel dissonance.

Table 7.1: Dataset structure (all variables are categorical unless indicated otherwise)

Category	Variables				
Personal characteristics	Region of home location, region of workplace location	Sex, income, ethnicity, residence ownership, language, school level, home size, family type, occupation, reduced mobility	Age (number and categories)	Ownership of credit or debit card, smartphone, tablet, smart car, smartwatch, social media profiles, navigation apps (e.g., Google Maps)	Access to bus stations, metro, commuter rail, etc.
Travel behaviour	Days/week commuted away from home for work	Drive to work, electric vehicle ownership, having public transport pass, subscription to: carshare, carpool service, bikeshare	Number of vehicles (cars, motorcycles, scooters, etc.)	Frequency of use of different modes	Probability of using different modes
Attitudes	How important is the following criteria for you to choose a mode (1-10)? (E.g.: easy to use, easy to plan, affordable.)	Does your current mode fulfill the criteria (binary): easy to use, easy to plan, affordable, etc.	Adjectives to describe modes (metro, bus, car, bike, walking, etc.): possibility of choosing from 66 different adjectives		
Mode	Current mode: what is your main mode of transport?	Preferred mode: If you had the choice, which mode would you prefer for your most frequent trips (work, study, etc.)?			

7.3.2 Methods

To assess travel dissonance, we compared respondents' answers about current mode choice and preferred mode. We considered nine categories of consonance and dissonance (each labelled as Current Mode-Preferred Mode), with the first three being consonant users: Car-Car, Public Transport-Public Transport, Active-Active. The six remaining are dissonant users: Car-Public Transport, Car-Active, Public Transport-Car, Public Transport-Active, Active-Car, and Active-Public Transport. The category “car” includes motorcycle users, the “public transport” category combines all types of public transport, and the “active” category combines walking and cycling. Using these categories, we constructed alluvial plots and used chi-squared test to assess whether there is a significant difference in the distribution of dissonance categories between genders.

Then, to shed light on the factors explaining why certain individuals use the car, even when it is not their preferred mode, we specifically investigated car users’ (n = 2,436) attitudes. Following a gender perspective, we explored the relationships between attitudes toward mode choice and towards different modes, and the type of dissonance for women and men. The three dissonant types are as follows: non-dissonant car users (Car-Car), car users who would prefer to use active modes (Car-Active), and car users who would prefer to use public transport (*Car-Public Transport*). To conduct the analysis, two sets of variables were selected: 24 criteria ratings based on the question *How important is the following criteria for you to choose a mode?*; and adjectives selected by the respondent to describe the different modes of transport.

Starting with the responses to the rating of the 24 criteria used in choosing a mode (scale 1-10), for each individual, we generated z-scores based on the mean and standard deviation of the rating of the 24 criteria to capture how each individual values different criteria relative to the others. This enabled analyzing the relative importance of each criterion, as reported by every individual. With the z-scores, we assessed gender differences in the rating of the criteria used in choosing a mode. For each criterion, the differences in the mean of the z-scores between men and women were assessed using Welch Two Sample t-tests (Welch, 1947), which are suitable for comparing groups of different sample sizes.

The next analysis focused on the adjectives selected by the respondents for each mode. For each mode (bus, metro, walking, cycling), respondents were asked to select from a number of adjectives (up to 17 out of 66) that describe the given mode. First, using the ten adjectives most often

mentioned by car users (men and women together) to describe each mode, we performed chi-squared tests of the number of men and women that mentioned a given adjective, and the number of those who did not, to understand whether there are differences in the distribution of how men and women perceive/describe each mode. We also generated bar plots to illustrate the main differences.

Given the large number of variables included in the previous analyses, we performed a factor analysis to reduce the number of variables and examine their aggregated effects. To this end, the following variables were included in the initial factor analysis: the rating of the 24 criteria to choose a mode (24 variables), and the binary variables associated with the five adjectives most frequently attributed to each mode (five variables for each mode – bus, metro, walking, and cycling – for a total of 20 variables). We also tested ten adjectives per mode, but ultimately decided on five to facilitate the robustness of loadings, and interpretability. Two factor analyses were conducted separately, one per gender, to distinctly assess women's and men's attitudes. To start testing the number of factors, we used the Very Simple Structure (vss) function from the *Psych* package in R (Posit Team, 2025), with the Velicer MAP test (Velicer et al., 2000), which identifies the point where adding additional components stops improving the explanation of shared variance, and the BIC test (Schwarz, 1978), which balances fit and complexity, penalizing models with larger parameters. All metrics in the function pointed towards 6-8 factors. We iteratively assessed the optimal number of factors evaluating a combination of the BIC criteria, the explained variance, correlations between factors, and factor complexity using an oblique rotation, to allow for correlated factors. Finally, we opted for six factors, because the mean item complexity was lower, implying lighter and fewer cross loadings, as the models with the strongest explanatory power, interpretability, and best mean factor complexity. We excluded variables with a loading of <0.45 on any factor, ending with a total of 33 variables for women and 32 for men. To describe the factors and understand how they vary across dissonance categories, we then calculated factor score averages, per gender, grouped by dissonance types, and performed ANOVA tests to look for significant differences between types.

Lastly, to further understand how these attitudes and perceptions were associated with men's and women's dissonance, we generated multinomial logit regressions with the dissonance category as the dependent variable, while controlling for individual and attitudinal characteristics. Specifically, we modelled the likelihood of belonging to the Car-Public Transport and the Car-Active dissonance

type, as compared to the non-dissonant type Car-Car. As for the independent attitudinal variables, we first included the factor scores from the previous analysis, and then followed a parsimonious stepwise approach to generate the regression model, first testing the inclusion of factor variables one at a time with likelihood-ratio tests. We then controlled for socio-economic characteristics, again tested in a stepwise approach. Lastly, we included specific variables from the original 24 criteria used in choosing a mode that showed significantly different patterns between genders in the exploratory analysis, but that were not included in the results of the factor analysis. This enabled capturing some key variables that were not correlated with other variables. We tested them, as with all other variables, using likelihood-ratio tests to assess their contribution to the model. These variables were *Importance that the mode is affordable* and *Importance that the mode is ecological*. We tested a regression including both men and women, with gender as a control variable. Given that the gender variable was significant (at a 99% confidence interval), we decided to present two different regressions, one per gender, to examine the determinants of dissonance specifically for women and men.

7.4 Results

7.4.1 Is there travel dissonance and does it vary by gender?

Looking at the travel mode currently used against the respondent's preferred mode, we find the existence of dissonance, as well as differences between genders (**Figure 7.2**). Overall, 34% of women and 33% of men reported a dissonance. The most pronounced gendered differences are between the 23% of men who currently cycle/walk and would prefer using the car, versus 18% of women that report this same dissonance. Conversely, 35% of women currently use public transport and prefer the car, while 30% of men report this type of dissonance. Looking specifically at car users, those who do not experience dissonance accounts for almost 75% of both men and women. Yet, there is a smaller proportion of women whose ideal mode would be public transport (15% vs. 17% of men), but a higher proportion of women who would prefer using active modes (11% vs. 8%). Results suggest that more women tend to report dissonance related to public transport as their current mode, while men have more dissonance related to active modes as the current mode. A chi-squared test found a statistically significant difference between genders in the distribution of dissonance categories (X-squared = 43.493, df = 8, p-value = 7.092e-07).

When looking at the overall percentages, if everyone travelled by their preferred mode, active modes would lose 2-4% of users for both genders, car would lose 10% of women and 7% of men, and public transport would gain 6% of women and 9% of men. The results highlight the potential to decrease car dependency in the region, namely by supporting public transport trips.

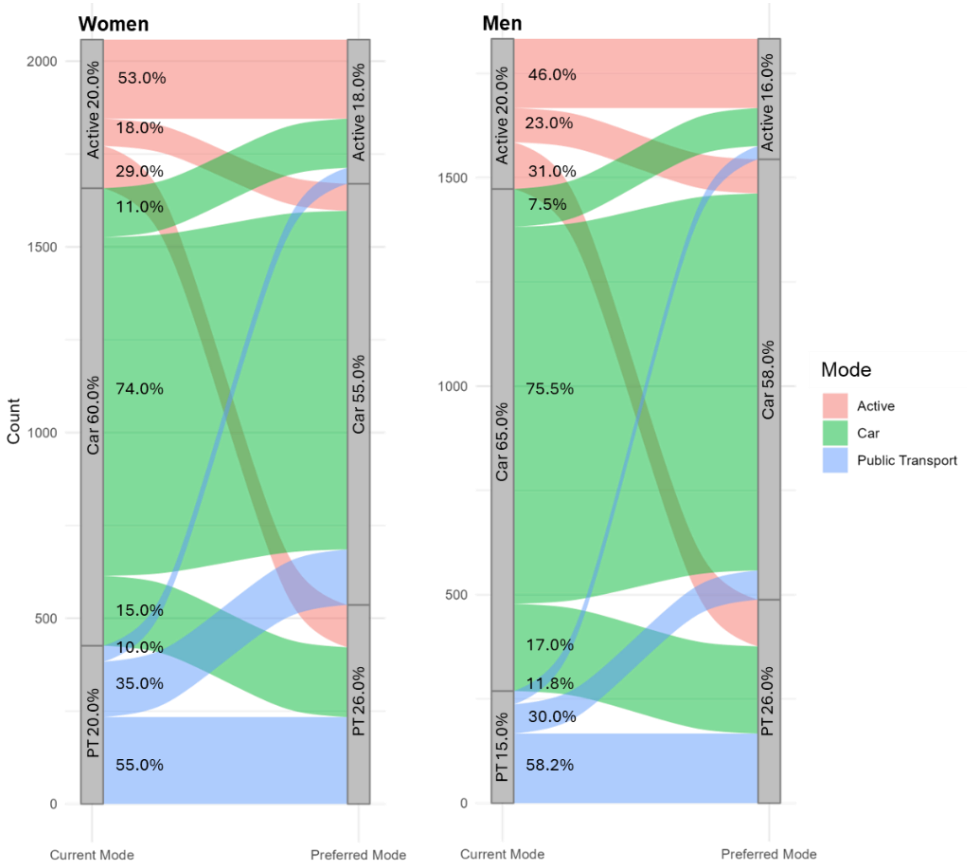

Figure 7.2. Alluvial plots of proportions of dissonance categories (current mode versus preferred mode), by gender. (PT = public transport.)

7.4.2 How do attitudes between car users vary for women and men?

Although the gender differences in dissonance among car users are relatively small, the remainder of the paper explores whether they could be explained by different factors for men and women, as understanding these factors is instrumental in designing strategies to reduce car dependency. To first understand how attitudes towards mode choice vary between gender, **Table 7.2** shows the differences in the relative importance (z-score) of the 24 mode choice criteria between women and men (for car users only). The table is ordered based on the coefficients, with positive coefficients in the top rows and negative one in the bottom rows. A positive estimate difference indicates a

higher rating by women (group 1). Findings show several statistically significant differences, highlighted in bold red text in the table.

Results indicate that for women car users, it is more important than for men that their mode is state of the art, gives them a sense of pride, is not physically demanding, is comfortable, and is reliable. Conversely, for men, it is more important than for women that their mode agrees with their lifestyle, makes them feel safe, is not stressful, allows them to be in their own bubble, and is close by. Overall, for women car users, the aspirational aspects of car use appear to be more important than for men, as they rate higher than men that the mode is perceived as the state of the art and that it gives them a sense of pride. Women also rate higher several practical aspects (not physically demanding, reliable, and comfortable), whereas men value less tangible aspects, such as agrees with my values and lifestyle, allows me to be in my own bubble, and is less stressful, alongside a feeling of safety.

Table 7.2: Results of t-tests of gender differences in mode choice criteria relative rating (significant differences within a 95% confidence interval level in bold red text), ordered by coefficients. A positive estimate difference indicates a higher rating by women.

		Group 1: *Women* (n = 1232) Group 2: *Men* (n = 1204)	
Variable: That the mode (...)		**Estimate difference**	**p-value**
Is state of the art	Positive estimate difference →	**0.427**	**<0.001**
Gives me a sense of pride		**0.158**	**0.002**
Is not physically demanding		**0.138**	**0.002**
Allows me to have time for myself		0.062	0.095
Is comfortable		**0.058**	**0.020**
Is reliable		**0.055**	**0.014**
Is sheltered from weather		0.025	0.406
Gives me a sense of freedom		0.023	0.505
Offers predictable travel time		0.020	0.444
Makes it easy to plan a trip		0.010	0.662
Is ecological		0.009	0.852
Is easy to use	← Negative estimate difference	-0.009	0.677
Is affordable		-0.029	0.369
Allows me to feel well physically and mentally		-0.029	0.336
Lets me be autonomous and in control		-0.031	0.269
Offers the most direct trip		-0.031	0.194
Offers the fastest trip		-0.049	0.059
Is clean		-0.055	0.084
Is close by		**-0.055**	**0.026**
Allows me to be productive/maximize my time		-0.082	0.068
Allows me to be in my own space/bubble		**-0.115**	**0.006**
Is not stressful		**-0.130**	**<0.001**
Makes me feel safe		**-0.162**	**<0.001**
Agrees with my values/lifestyle		**-0.208**	**<0.001**

It is important to note that the statements are subject to interpretation. For example, the state of the art, sense of pride, and lifestyle-related statements could be interrelated and interpreted differently by men and women. To overcome this limitation, a factor analysis was conducted, grouping similar aspects in a single factor (see **Section 7.4.4**).

7.4.3 What do men and women think of each mode?

In this section, we focus on the ten adjectives cited most often for each mode, and the analysis is again restricted to car users. While the previous analysis considered the criteria used in choosing a mode, the questions were not mode specific. In this section, mode-specific attitudes are examined, which enables us to better understand how men and women perceive different modes. For each mode, the relative number of occurrences of each of the ten adjectives is compared across genders (proportion of men/women having selected the adjective). The full chi-squared test results can be found in **Appendix C**, while **Figure 7.3** only displays statistically significant results. The percentage of mentions by gender is presented, with adjectives with a positive connotation on the positive x-axis, and vice-versa for the ones with a negative connotation.

Looking first at the adjectives mentioned for public transport (metro and bus), results show that a greater proportion of women car users think that the metro does not support their lifestyle, and is busy, dirty, stressful, and fast. This corresponds to a total of four negative and one positive adjectives. As for the bus, women report, again in a greater proportion than men, that it is busy, dirty, painful, and easy to access, for a total of three negative adjectives and one positive. Overall, women who are currently car users seem to think worse of public transport than men car users do, although they report in a greater proportion that the metro is fast and that the bus is easy to access. This may suggest that while they recognize the practical advantage of these modes, they perceive several disadvantages, mostly related to comfort.

As for the active modes, in general, women who are currently car users think more positively of walking than men, and more negatively about cycling. First, we observe that a greater proportion of women think that the bike does not support their lifestyle and is uncomfortable, while a greater proportion of men think that the bike is quiet. With respect to walking, more women think that it is affordable and ecofriendly, but slow. This result suggests that the aspect of speed may be more important for women (fast for metro, slow for walking) than for men.

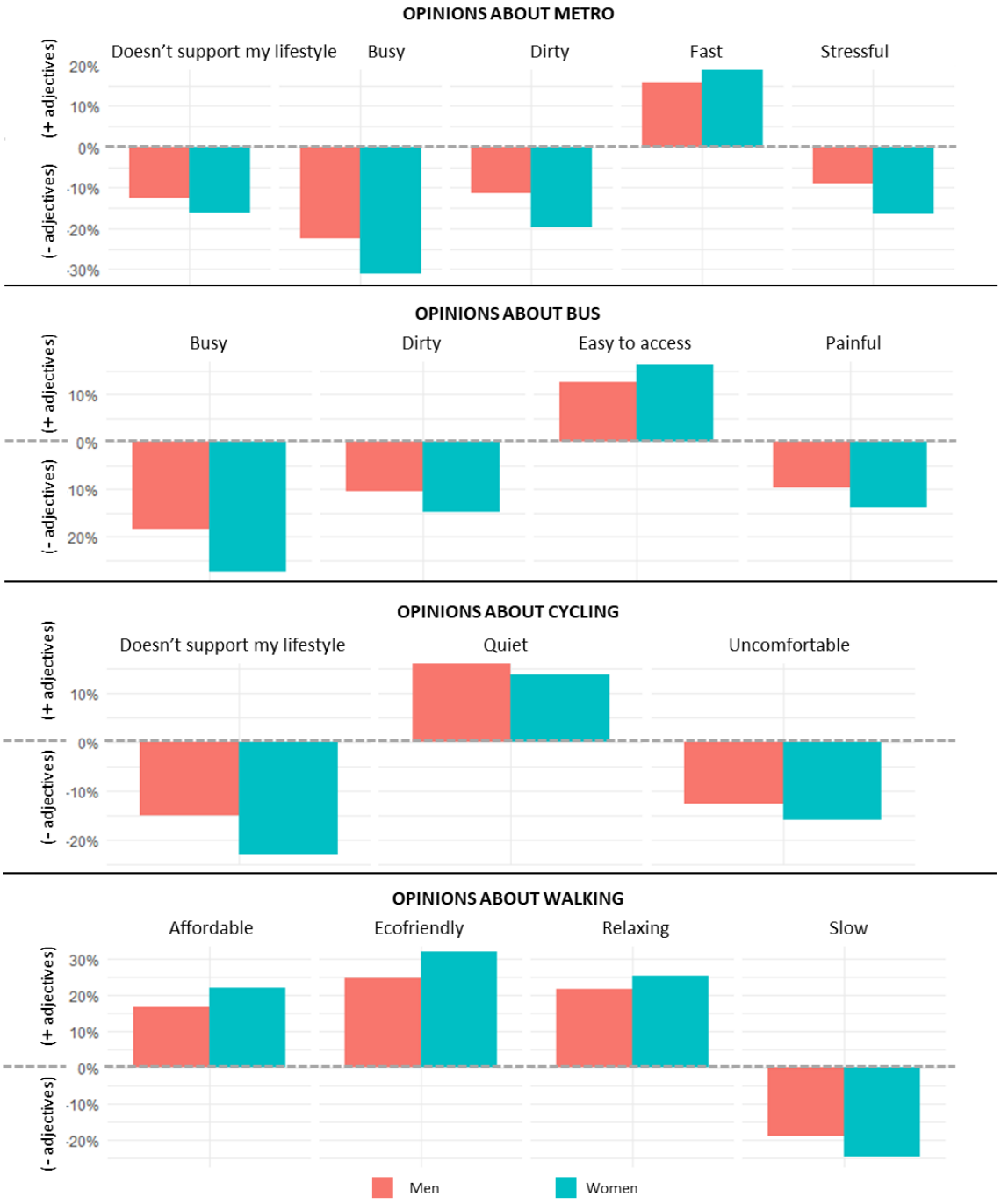

Figure 7.3 Chart showing the proportion of women and men who selected particular adjectives to describe a travel mode (only adjectives with a significant difference at 95% confidence interval between genders are presented)

7.4.4 What are the main dimensions that drive opinions and attitudes towards travel modes? (factor analysis)

To assess the aggregated effects of the different variables, we conducted factor analyses. **Table 7.3** shows the results of the factor analysis with the loadings of each variable for men and for women. Two factors (factors 1 and 2) are related to broad aspects of trip and travel, whereas the four remaining ones directly relate to opinions about the modes. The first factor, *Importance of Trip Quality*, is composed of variables related to trip characteristics: that the mode offers predictable travel time, is easy to plan, to use, is reliable, etc. The second factor, *Importance of How the Mode Makes Me Feel*, consists of variables related to less tangible aspects: that the mode gives me a sense of pride, time for myself, agrees with my values/lifestyle, allows me to feel productive, etc. These two factors help make a clear distinction between "objectively" measurable trip characteristics (factor 1) and broader, feeling-related aspects (factor 2). The four other factors are specific to the different modes: Perception of Walking, of Cycling, of Metro, and of Bus.

The total variance explained by the factors (proportion var. in the table) is similar for women and men, but the distribution of explained variance differs markedly by gender. Among men, the trip quality factor emerges as the dominant dimension, accounting for 12 % of the total variance, compared to 9% among women. For women, the factor about how the mode makes them feel has a variance as high as the trip quality factor, whereas it is lower for men. Moreover, women's explained variance is more evenly distributed across factors, suggesting a more multidimensional structure of travel attitudes, whereas men's attitudes are more strongly organized around a limited number of dominant dimensions.

The factor *Importance of Trip Quality*[5] includes, for both men and women, the following variables: that the mode offers predictable travel times, is reliable, is close to access, is easy to plan, and is easy to use. For men, however, three additional variables are also included in this factor: trip speed, directness, and comfort.

As for the factor *Importance of How the Mode Makes Me Feel*[6], the following variables are included for both genders: that the mode allows time for oneself, allows to be mentally and physically well, allows to be in one's own bubble, gives a sense of pride and freedom, and agrees

[5] *"Importance of Trip Quality"* is more about instrumental/functional considerations.
[6] *"How the mode makes me feel"* is about an individualistic mobility orientation, as opposed to affect/emotions.

with one's values. It is interesting to note that for women, the comfort criteria loads higher in this factor than in the *Trip Quality* factor, whereas for men, it loads higher in the *Trip Quality* factor. This may reflect that the comfort relates to a more general wellbeing aspect for women, whereas for men, it is more a practical matter. Similarly, for women, that the mode allows autonomy and control is present in this factor (and not for men), again related to a broader notion of wellbeing. For men, the criteria state of the art is included in this factor.

Looking now at the mode-specific factors, it is important to note key distinctions between genders: factors 3, 4, and 5 reflect mixed perceptions for women, whereas they reflect positive perceptions for men. They were thereby named differently for women and men (Mixed Perception and Positive Perception respectively). As for factor 6, it reflects negative perceptions for both men and women, thereby a common name was attributed to both (Negative perception). Starting with this 6th factor, the Negative Perception of Bus factor is solely composed of negative adjectives for both genders: busy, slow, restrictive, and unsupportive of one's lifestyle (men and women); and uncomfortable (men only). As for the metro (factor 5), the positive variables ecofriendly and fast load positively for both genders (in addition to efficient for men), whereas three variables with a negative connotation appear for women: busy, hard to access, and dirty. In line with the previous results, this suggests a more nuanced perception among women. While men that selected positive adjectives tended to only select positive adjectives, women tended to select both positive and negative adjectives.

Similar results are observed for the Perception of Cycling factor (4) and, to a lesser extent, for the Perception of Walking factor (3). Starting with cycling, for men, the factor is composed of only positive adjectives (ecofriendly, affordable, quiet, and simple), while women have a mix of positives (ecofriendly and affordable) and negatives (doesn't support my lifestyle, slow, and dangerous). The Perception of Walking factor is also composed of only positive adjectives for men, whereas the adjective slow is present in this factor for women. These results again suggest that the notion of speed is more present among women.

Overall, with respect to the criteria used in choosing a mode, more criteria are associated with the *Trip Quality* factor for men than for women, and this factor explains a higher proportion of the variation. As for the mode-specific factors, women car users seem to perceive public transport and active modes in a more nuanced manner than men, considering both the advantages and

Table 7.3: Factor analysis, per gender.

	WOMEN							MEN					
	Factor 1 Importance of Trip Quality	**Factor 2** Importance of How the Mode Makes me Feel	**Factor 3** Mixed Perception of Walking	**Factor 4** Mixed Perception of Cycling	**Factor 5** Mixed Perception of Metro	**Factor 6** Negative Perception of Bus		**Factor 1** Importance of Trip Quality	**Factor 2** Importance of How the Mode Makes me Feel	**Factor 3** Positive Perception of Walking	**Factor 4** Positive Perception of Cycling	**Factor 5** Positive Perception of Metro	**Factor 6** Negative Perception of Bus
SS loadings	3.09	3.11	2.22	1.91	1.88	1.59	SS loadings	3.91	2.92	1.62	1.90	1.23	1.90
Proportion var.	0.09	0.09	0.07	0.06	0.06	0.05	Proportion var.	0.12	0.09	0.05	0.06	0.04	0.06
	Loadings							**Loadings**					
Offers predictable travel time	0.69						Offers predictable travel time	0.74					
Is accessible/close by	0.82						Is accessible/close by	0.72					
Is easy to plan a trip	0.77						Is easy to plan a trip	0.80					
Is easy to use	0.79						Is easy to use	0.80					
Is reliable	0.75						Is reliable	0.72					
							Offers the fastest trip	0.56	0.16		0.11		
							Offers the most direct trip	0.61	0.14				
							Is comfortable	0.47	0.31				
Allows me to have time for myself		0.62					Allows me to have time for myself		0.62				
Gives me a sense of pride	-0.23	0.54					Gives me a sense of pride	-0.24	0.73				
Agrees with my values/lifestyle		0.56					Agrees with my values/lifestyle		0.61				
Gives me a sense of freedom		0.72					Gives me a sense of freedom	0.17	0.59				
Allows me to feel well physically and mentally		0.57					Allows me to feel well physically and mentally	0.21	0.55				
Allows me to be in my own space/bubble		0.66					Allows me to be in my own space/bubble		0.59				
Allows me to be productive/maximize my time		0.46					Allows me to be productive/maximize my time		0.51				
							Is state of the art		0.46		0.10		
Is comfortable	0.22	0.54											
Lets me be autonomous and in control	0.19	0.55											

Table 7.3: Factor analysis, per gender. (continued)

	WOMEN							MEN					
	Factor 1 Importance of Trip Quality	**Factor 2** Importance of How the Mode Makes me Feel	**Factor 3** Mixed Perception of Walking	**Factor 4** Mixed Perception of Cycling	**Factor 5** Mixed Perception of Metro	**Factor 6** Negative Perception of Bus		**Factor 1** Importance of Trip Quality	**Factor 2** Importance of How the Mode Makes me Feel	**Factor 3** Positive Perception of Walking	**Factor 4** Positive Perception of Cycling	**Factor 5** Positive Perception of Metro	**Factor 6** Negative Perception of Bus
Bus – Busy						0.62	Bus - Busy						0.62
Bus - Doesn't support my lifestyle						0.59	Bus - Doesn't support my lifestyle						0.62
Bus - Slow						0.66	Bus - Slow						0.61
Bus - Restrictive						0.64	Bus - Restrictive						0.61
							Bus - Uncomfortable						0.58
Metro - Ecofriendly					0.63		Metro - Ecofriendly					0.56	
Metro - Fast					0.59		Metro - Fast					0.65	
							Metro - Efficient					0.69	
Metro - Busy					0.72								
Metro - Hard to access					0.46								
Metro - Dirty					0.62								
Cycling - Ecofriendly				0.65			Cycling - Ecofriendly				0.69		
Cycling - Affordable				0.64			Cycling - Affordable				0.73		
							Cycling - Quiet				0.71		
							Cycling - Simple				0.60		
Cycling - Doesn't support my lifestyle				0.62									
Cycling - Slow				0.65									
Cycling - Dangerous				0.50									
Walking - Ecofriendly			0.76				Walking - Ecofriendly			0.61			
Walking - Relaxing			0.63				Walking - Relaxing			0.65			
Walking - Simple			0.63				Walking - Simple			0.63			
							Walking - Pleasant			0.64			
Walking - Slow			0.53										
Walking - Affordable			0.73										

disadvantages of these modes. The only exception is for the bus, where both men and women agree on only negative adjectives.

7.4.5 How dissonance affects attitudes and how they vary by gender?

Table 7.4 shows the average factor scores per gender grouped by dissonance type. It is important to note that since two distinct factor analyses were conducted, it is not possible to compare the scores across genders. For both men and women, those with a dissonance towards active modes have a slightly below average (0) score in the factor *Importance of Trip Quality*, meaning they give less importance to the practical trip characteristics than car consonant users and public transport dissonant ones. Both dissonant groups (Car-Active and Car-Public Transport) show a below average score in the factor *Importance of How the Mode Makes me Feel,* implying that a sense of pride, agreement with lifestyle, autonomy, personal space, etc. are more important factors for car consonant users. This difference between consonant and dissonant users is statistically significant for both genders in the Car-Active type, and for women as well in the Car-Public Transport dissonance type. For both men and women, those in the Car-Public Transport dissonance type ranked below average in the *Negative Perception of Bus* factor, implying that those with a dissonance towards public transport have a less negative view of the bus that the other two types. This difference is statistically significant for men.

Regarding factors 3, 4 and 5 (walking, cycling, metro), we consistently observe that dissonant men think more positively about the bike, walking, and metro than do consonant ones, as they rank above average in the factors of positive perception of the three modes. Men's positive perception of the metro is statistically significantly different between both dissonance types and consonant ones. Conversely, consonant car users have a more negative perception of these modes, which may explain why they prefer using the car.

As for women, there seems to be smaller differences between the different dissonance types, which is likely due to the fact that the factors represent mixed opinions. Further, it is more difficult to interpret the results given the more nuanced opinions of women towards different modes.

Table 7.4: Average factor scores per dissonance type, per gender. Red text indicates statistically significant differences from the consonant type.

WOMEN

Dissonance	**Factor 1** Importance of Trip Quality	**Factor 2** Importance of How the Mode Makes me Feel	**Factor 3** Mixed Perception of Walking	**Factor 4** Mixed Perception of Cycling	**Factor 5** Mixed Perception of Metro	**Factor 6** Negative Perception of Bus
Car-Car	*0.013*	*0.081*	*-0.018*	*0.027*	*0.004*	*0.010*
Car-Active	-0.120	-0.210	-0.013	-0.097	-0.004	0.038
Car-Public Transport	0.024	-0.241	0.097	-0.064	-0.016	-0.076

MEN

Dissonance	**Factor 1** Importance of Trip Quality	**Factor 2** Importance of How the Mode Makes me Feel	**Factor 3** Positive Perception of Walking	**Factor 4** Positive Perception of Cycling	**Factor 5** Positive Perception of Metro	**Factor 6** Negative Perception of Bus
Car-Car	*0.013*	*0.047*	*-0.013*	*-0.030*	*-0.056*	*0.033*
Car-Active	-0.225	-0.229	0.121	0.146	0.230	0.048
Car-Public Transport	0.043	-0.102	0.001	0.066	0.141	-0.164

In red: Statistically significantly different from consonant type (Car-Car)

7.4.6 What are the factors associated with dissonance for each gender? (multinomial logit regression)

Table 7.5 contains summary statistics of the variables included in the model. **Table 7.6** shows the results for the regression analyses for men and women. Looking first at the attitudes and opinions, we observe several variables that are statistically significant for both genders (shaded gray in the table). First, for both women and men, the factor *Importance of How the Mode Makes Me Feel* is associated with a lower likelihood of being dissonant (Car-Public Transport and Car-Active) as compared to the base category (Car-Car). In other words, car users who rate highly criteria such as sense of pride, sense of freedom, values/lifestyles are more likely to be consonant drivers compared to those who would prefer using public transport (and active transport, though to a lesser extent). In addition, the Importance that the mode is affordable is positively associated with a higher likelihood of dissonance (Car-Active) for both genders. Similarly, the Importance that the mode is ecological variable is associated with a higher likelihood of being dissonant (Car-Public Transport and Car-Active), as compared to the base category (Car-Car). Notably, the factor *Importance of trip quality* is not a statistically significant determinant of dissonance type for either gender.

Table 7.5: Summary statistics of the variables used for car users for the multinomial logit regressions.

		WOMEN		MEN	
Variable	**Category**	**n**	**%**	**n**	**%**
Age	18-34	456	37.9	120	10.2
	35-44	200	16.6	156	13.2
	45-54	177	14.7	185	15.7
	55-64	183	15.2	271	23
	65 +	188	15.6	446	37.9
Region	Downtown	8	0.7	18	1.5
	Central	206	17.1	122	10.4
	Couronne Sud	188	15.6	192	16.3
	Laval	139	11.5	154	13.1
	Longueuil	133	11	161	13.7
	Residential (North)	124	10.3	82	7
	Residential (South)	187	15.5	137	11.6
	Couronne Nord	219	33.8	312	42.8
Occupation	Other	114	9.5	34	2.9
	Retired	260	21.6	518	44
	Student	117	9.7	16	1.4
	Work	713	59.2	610	51.8
Owning PT card	No	779	64.7	816	69.3
	Yes	425	35.3	362	30.7
Subscription to carshare	No	1180	98	1153	97.9
	Yes	24	2	25	2.1
Residence ownership	Owner	751	62.4	872	74
	Renter	453	37.6	306	26
Highest school level	Primary or less	8	0.7	4	0.3
	Secondary	252	20.9	296	25.1
	University/College	944	78.4	878	74.5

While there are common attitudes and opinions that appear to be determinants of dissonance for both men and women, a few differences can be observed. First, for women, regarding the mode-specific perception factors, their inclusion did not yield more informative models (log likelihood test not significant), nor were the coefficients statistically significant. For men, the *Positive Perception of Metro* and the *Negative Perception of Bus* factors showed statistical significance; when opinions about metro are positive, men are more likely to show a Car-Active dissonance. When opinions about the bus are negative, they are less likely to be Car-Public Transport dissonant. Whereas it is to be expected that the *Mixed Perception* factor does not yield statistically significant results, it is interesting to note that the *Negative Perception of Bus* is not significant for women, although it is for men (a negative opinion associated with a dissonance towards public transport). In line with this, whereas the affordability of the mode is only significant for the Car-Active dissonance for women, it is also statistically significant for the Car-Public Transport dissonance

type for men; the more important the affordability aspect, the more likely are men to be dissonant users of public transport. Overall, the results suggest that the dissonance towards public transport is explained by practical trip aspects more for men than for women.

Looking at individual characteristics, we observe some similarities between men and women. Public transport pass owners are more likely to be dissonant (both dissonance types) and both retired men and women are less likely to be Car-Active dissonant.

Most notably, there are several differences between men and women in individual characteristics. The first notable difference is that women's dissonance is determined by more socio-economic variables as compared to men. In fact, three socio-economic variables showed no significance in the men model: education level, subscription to carshare services, and residence ownership. Therefore, the results suggest that men's dissonance may be better explained by attitudes and opinions. Conversely, individual characteristics are more influential for women: women with their highest level of education being secondary (as compared to university) are more likely to be consonant car users and women with their highest education level being primary are more likely to be Car-Active dissonant. Further, women who are students are more likely to be consonant car drivers than active dissonant. Finally, women who rent their homes are less likely to be Car-Public Transport dissonant.

Overall, while more efforts would be required to explain the relationships observed above (namely through spatial data), the regression results show that women's travel dissonance is more closely associated with socio-economic characteristics than for men (namely education level and occupation), while, for men, opinions and feelings about transport modes have a more determinant role in travel dissonance.

Table 7.6: Multinomial logit regression results, per gender. Cells shaded in gray are significant for both, in blue are significant for women only, in green are significant for men only.[7]

		WOMEN *McFadden R2: 0.11 Log-likelihood: -804.21*		**MEN** *McFadden R2: 0.12 Log-likelihood: -748.01*	
		Car-Active	**Car-Public Transport**	**Car-Active**	**Car-Public Transport**
Variable		*Estimate Sig.*	*Estimate Sig.*	*Estimate Sig.*	*Estimate Sig.*
Attitudinal variables					
Intercept		-5.289 ***	-4.551 ***	-5.006 ***	-5.112 ***
Factor importance of trip quality		-0.115	0.161	-0.229	0.137
Factor importance of how the mode makes me feel		-0.529 ***	-0.604 ***	-0.460 **	-0.541 ***
Factor (**mixed** for women, **positive** for men) opinion about metro		-0.034	-0.004	0.337 **	0.166
Factor **negative** opinion about bus		0.139	-0.014	0.058	-0.256 *
Importance that the mode is affordable		0.244 **	0.051	0.207 *	0.184 **
Importance that the mode is ecological		0.207 ***	0.326 ***	0.146 **	0.265 ***
Individual characteristics					
Owning public transport card *Base: No*	Yes	0.169	0.902 ***	0.436	1.288 ***
Subscription to carshare *Base: No*	Yes	1.800 **	1.262 *	0.563	0.960
Highest level of education *Base: University*	Secondary	-0.705 *	-0.567 *	0.013	-0.410
	Primary	1.599 *	-14.909	-13.925	-14.303
Occupation *Base: Work*	Retired	-0.764 **	-0.092	-0.533 *	-0.351 *
	Student	-0.838 *	-0.308	-0.071	-0.519
	Other	-0.248	0.059	-1.537	-0.539
Residence ownership *Base: Owner*	Renter	-0.342	-0.604 **	-0.018	-0.516

Significant only for women
Significant only for men
Significant for both

7.5 Discussion and conclusion

The analysis of the relationships between gender, travel dissonance, and attitudes sheds light on key differences between men and women. In relation to the proportion of consonant-dissonant travellers and gender, our study found that women have a larger Public Transport-Car (*current mode-preferred mode*) dissonance (35% women, 30% men). We also found that men experience more Active-Car dissonance (18% women, 23% men). Yet, we found an overall similar proportion

[7] These models were also tested controlling for age group, and the main differences between genders remained stable.

of dissonant car users among women (26.0%) and men (24.6%). These results differ from previous research, where Hu et. al (2023) observed a greater proportion of car user dissonance among women (56.7% women and 47.9% men). Comparatively, in our study, car consonants are the larger proportion, as 78% of women and 62% of men are consonant with their travel mode. The variations in dissonance and gender in different cities might suggest that travel consonance and dissonance, particularly when analyzed from the gender perspective, is highly dependent on context, likely both geographic and cultural. In this sense, and given the limited number of studies, our findings suggest further direction for study, stress the need to collect appropriate data, and perform these analyses locally.

Our findings reveal important gender differences related to attitudes and dissonance. Women car users rate significantly higher than do men, aspirational/value aspects, such as that their mode gives them a sense of pride and is perceived as state of the art. In a similar vein, other studies have found that the car is the mode most commonly associated with luxury and status, though without gender disaggregation (Mella-Lira & Paez, 2021). On the other hand, women car users also rate higher than do men aspects like comfort and reliability, aspects that are more rarely analyzed from the gender perspective, both in dissonance studies and in transit planning. Mella-Lira & Paez (2021) found that car users identified enjoyment and happiness as affective values of the car (79% and 71%, respectively), but do not report results disaggregated by gender. These concepts require further investigation, especially with multivariate analyses that can show how they interact with different groups of users and dissonance types.

In line with this, the factor analysis reveals that the less tangible aspects of travel (*How the mode makes me feel*) includes a broader array of variables for women, namely the comfort, autonomy, and control variables. These less tangible aspects of trips (*How the mode makes me feel*) appear to be a key determinant of dissonance for both men and women, whereas practical aspects of travel do not relate significantly to dissonance. These findings shed light on the importance of going beyond the practical trip characteristics to understand women's and men's attitudes and dissonance.

The regression results also show that women's dissonance is more associated with socio-economic factors, whereas men's dissonance is more associated with feelings and opinions about the public transport system, and some practical aspects of trips, like affordability. This result connects with previous research that showed that women are systematically more transport poor than men across

Canada, due to socio-economic factors (M. L. Guerrero-Balarezo et al., 2025), suggesting that women may be more influenced by these factors than men. Along the same line, D'Agostino et al. (2024) highlight that women's mobility outcomes appear more sensitive to variations in income, household composition, and transport accessibility compared to men's. In this case, if women are constrained to a mode they do not prefer due to socio-economic reasons combined with the lack of options, the attitudinal factors may be less determinant in terms of travel dissonance. This is a key distinction that warrants future study, namely in terms of mode captivity.

As for the perception of each mode, we found that women car users have an overall more nuanced perception of public transport and active modes as compared to men, who speak about the modes more positively. This is in line with a study by Beirão & Cabral (2008), who found, on average, that men expressed more positive attitudes toward public transport than did women. The findings also suggest that women consider the mode's speed when describing the modes, whereas this is not the case for men. This could be related to travel time optimization (S. Roy et al., 2024). Further research could investigate the perception of car dependency of these users, as well as the interactions with control, freedom, autonomy, and anxiety associated with the car, as suggested by Freudendal-Pedersen (2020), who studies the role of freedom, happiness, and other values in creating practices of everyday mobility.

Although the dataset provides a rich array of attitudes and opinions about transport-related matters, some limitations remain. The absence of a question about travel satisfaction did not allow for determining if consonance with a given mode is actively chosen. Some terms used in the questionnaire are ambiguous and could be clarified in the questionnaire to ease interpretation, such as "state of the art" and safety, which can be interpreted in the sense of crime, or in the sense of crashes and traffic. Finally, for the mode variables, the questions refer to the mode most frequently used; future studies could have more travel-specific information, (last-trip versus most frequent mode, etc.). This is one of the limitations of using secondary data sources to study perceptions, though it allowed for large-scale data collection that might not otherwise have been possible.

In relation to the analysis, future research could examine contextual characteristics of the respondents (home location, actual trip characteristics, proximity to public transport by type of service, etc.). Similarly, future research can delve into the multivariate analyses to explore the distinct gendered effects of location variables on travel dissonance. In terms of policy, future

research can study how interventions in public transport services and the built environment influence attitudes about modes, satisfaction, and dissonance between genders. Futures efforts of data collection and research should also focus on the ordeals of non-binary individuals, as their experience, especially in public transport, could be different but is not captured in existing data.

Using a dataset that combines travel behaviour, socio-economic variables, and attitudes about different aspects of transport, this study explored factors behind travel mode dissonance, to ultimately support designing strategies that reduce car dependency for both men and women. Our results show that men and women tend to experience travel dissonance differently, and that this sense of dissonance is associated with different attitudes and perceptions about transport modes, alongside socio-economic characteristics, especially for women. Since public transport agencies' travel surveys often focus predominantly on travel behaviour, these dimensions of attitudes and perceptions may be missed. Our findings underscore the need to systematically incorporate measures of perceptions into routine data collection practices, thereby enabling the development of policies that avoid disproportionately privileging some population groups, promoting gender equity in mobility policy and practice.

CHAPTER 8: DISCUSSION

This chapter synthesizes the findings and contributions of the thesis. Sections 8.1-8.3 discuss the results in light of the three research questions. Section 8.4 highlights the limitations of the thesis and section 8.5 discusses future avenues of research.

8.1 What are the differences in transport patterns between men and women? And how are these patterns expressed in space? (RQ1)

Prevalence of spatial gendered transport patterns

The results of the articles showed consistent, significant spatial differences across a diversity of transport phenomena between genders. Particularly, the most consistent pattern found was that there is a predominance of women moving in the suburban-pericentral areas, where there tends to be a level of transport disadvantage compared to central areas. The first article showed that areas where women experience more transport poverty, and especially lower levels of accessibility to destinations by active and public transport, are located in areas surrounding urban centres. In contrast, these patterns for men are present in central areas. The second article demonstrated that, in Montréal, women's destinations for work, accompanying trips, and leisure are in pericentral and suburban areas, while men's are more in the centre. The third article, also focused on Montreal, found that movement categories are the same between genders, but their spatial pattern across the metropolitan region differs; women move predominantly in the Local and Mixed-elongated movement types, both with multidirectional flows. **Figure 8.1** summarizes these results, showing how a muti-perspective framework (both in terms of topics and methodologies) is able to find relevant consistent spatial differences between genders. Relatedly, previous research has indicated that gender roles influence women's decision to have a more constrained radius, allowing them to work closer to home, meaning their patterns are more local (Meekes & Hassink, 2022), and that generally women travel shorter distances than men (Uteng, 2021). The Local movement types are located, again, in the central and pericentral areas for women, while they are attached to the CBD for men. Results also offer some nuance to this general pattern of local trips, as the Mixed-elongated type flows are in the Est suburban area for women, and see more intra-suburban movement, while for men, this movement type connects the suburban areas to the centre. The Est neighbourhood is one of the most economically disadvantaged in the city, and has a high proportion

of ethnic minorities, a result that connects to the one of Article 1, where transport poverty is found in or near suburban areas. Further, previous research has found that in suburban locations in North America, racialized women typically do not work close to home, and need to travel longer distances (Preston & McLafferty, 2016).

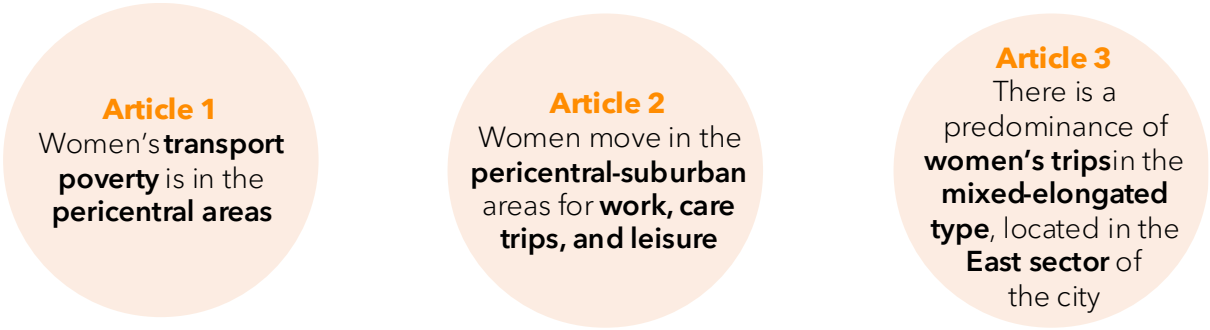

Figure 8.1 Summary of gender differences in spatial patterns.

Results demonstrate the need for planning authorities to conduct gender-aware analyses. These analyses should consider gender-sensitive data collection protocols for data collection and the inclusion of gender-oriented information in existing datasets. These analyses also need to incorporate gender-sensitive methods in statistical and spatial techniques.

In terms of planning implications, results suggest that modifications to transport services to support women's mobility freedom (Freudendal-Pedersen, 2016) should be directed to pericentral areas, to support the autonomous and discretional use of sustainable transport modes. These interventions could include not only improving suburban connections with city centres, but also intra-regional connections, as in Montréal, results showed several flows from women with low-incomes moving within the Est suburban region. Women's greater reliance on frequent, short trips means that systems with poor coverage or infrequent service have the effect of forcing women to take long, inefficient journeys. Therefore, strengthening public transport services in off-peak hours, when women tend to travel more, would support women's mobility needs, especially as bus services in Montréal currently have extensive spatial coverage in these areas, but low frequencies. Creative approaches, like combining traditional public transport interventions with semi-flexible stop-based micro-transit solutions, with fixed routes and the possibility of detours (Capodici et al., 2026), can also be tested to complement the spatial coverage and temporal flexibility for short- to mid-range

trips. Finally, policies that support autonomous mobility for children and the elderly in peri-central spaces can greatly support mobility freedom for women, by combining a set of community and infrastructural solutions.

Interaction between socio-economic characteristics and gendered transport patterns

Results across the four articles showed that, when exploring diverse transport topics, socio-economic factors intervene differently for men and for women in the relationship between movement patterns and a given phenomenon (transport poverty, dissonance, etc.). Overall, the results suggest that socio-economic factors play a greater role in explaining differences among women's travel. Article 1 showed that women are more transport poor than men across Canadian metropolitan areas, due mainly to a larger than average marginalization that is not compensated by land use and transport provision (accessibility). Article 2 showed that, in Montréal, income and the presence of children in the household are more closely associated with variations in women's travel distances. Article 3 found that the belonging of women's flows to a given movement type is more closely associated with socio-economic characteristics and access to public transport services, while men's is not significantly related to socio-economic or infrastructural factors in Montréal. Similarly, Article 4 demonstrates that women's dissonance is also associated with socio-economic factors, while men's is more related to attitudes towards transport. Similar to **Figure 8.1**, **Figure 8.2** summarizes the multi-perspective nature of the framework around these findings, here in the socio-economic aspect.

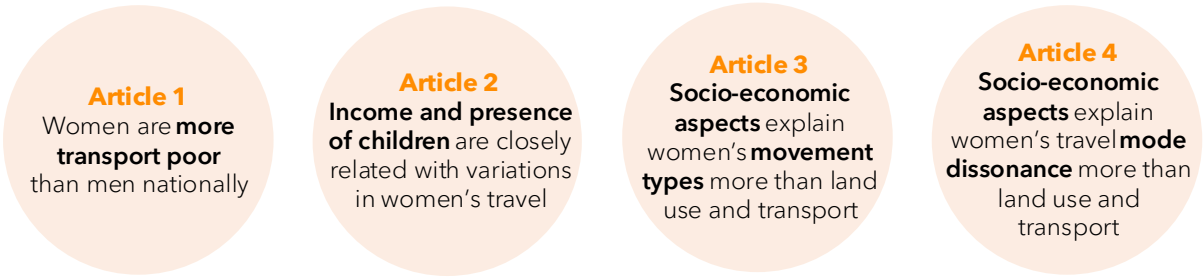

Figure 8.2. Summary of gender differences in socio-economic patterns.

Similar results have been found in the literature; a review by D'Agostino et al. (2024) summarizes that socio-economic and professional status affect women's daily travel distance and accessibility to jobs. The authors also note that unbalanced caregiving responsibilities disproportionally burden women, affecting destination types and travel time and mode. Women's mobility outcomes appear

more sensitive to variations in income, household composition, and transport accessibility, indicating a stronger dependence on external conditions when compared with men. While nuances apply to each of these analyses, a transversal pattern emerges where, overall, these results suggest that women are in general more captive to their travel conditions, in the sense of structurally constrained agency. Previous research has broadly mentioned that women are more often captive riders than men (Nobis & Lenz, 2005). These findings imply that existing land use and transport configurations may amplify socio-economic inequalities more strongly for women, as their daily mobility relies more heavily on proximity, service accessibility, and public transport provision.

8.2 In what ways does the interaction of land use and transport systems, together with individual characteristics, result in gendered transport patterns? (RQ2)

The diverse but interrelated topics analyzed in this thesis – travel behaviour, transport poverty, and travel dissonance – represent different facets of the transport domain. Travel behaviour reveals existing patterns, transport poverty captures structural aspects related to access to opportunities, while travel dissonance reflects on tensions between preferences and experienced realities. Examining these dimensions through a gendered perspective made it possible to identify disparities between men's and women's travel that might otherwise remain obscured. As such, the presented analyses focused on gender, splitting data and looking at the different effects the split produced, instead of using gender as a control variable.

By analyzing transport from multiple angles and consistently finding gendered patterns, the thesis demonstrates the pervasive effect of gender across different aspects of mobility. Gender is not only a demographic characteristic, but structures travel behaviour. Gender shapes rhythms of mobility, frames caregiving routines, and conditions safety perceptions (Law, 1999). Transport systems also reflect, reinforce, and reproduce gendered social roles. Gender thus emerges as an analytical category, essential for understanding how transport systems shape, and are shaped by, social inequalities (Sanchez de Madriaga, 2013). Further, aside from demonstrating the structuring nature of gender in mobility phenomena, by analyzing the three different topics through a variety of methods, this thesis proposes a multidimensional approach to studying gendered mobility inequalities.

The results of the articles, that found consistent differences between men and women, challenge gender-neutral approaches to analysis and planning, underscoring the need to incorporate a gender lens in planning. One of the clearest interactions derived from the results in the previous section is the pattern of women in pericentral areas with lower incomes experiencing transport poverty. This pattern shows how gender intersects with spatial and economic aspects to produce mobility constraints. In pericentral locations characterized by lower access to transport and lower land use diversity, women with low incomes end up systemically secluded from services and face transport challenges limiting social participation. Planning approaches that overlook these interactions may reinforce existing inequalities, even when pursuing goals of sustainable and equitable transport. Including gender as a dimension of mobility allows transport systems to be conceptualized as active components in the social production of urban space (Cresswell & Uteng, 2008).

8.3 How can existing data can be leveraged to better understand gender differences in transport? (RQ3)

Data

Across the thesis, different datasets were used: the Canadian Populations Census (Statistics Canada, 2016), Spatial Access Measures (Statistics Canada, 2023), the Montréal Origin-Destination Survey (ARTM, 2018), and the Montréal Segmentation Survey (ARTM, 2023b). The Montréal Origin-Destination (OD) survey's strongest advantage, from the perspective of gender analysis, is the richness of its socio-economic and demographic information, matched with information on travel behaviour and precise geographic locations. It allowed for understanding the social and spatial factors that condition travel behaviour, as demonstrated in the regressions used in Articles 2 and 3. Specifically, it revealed the effect of the presence of children in the household, which is one of the strongest drivers of gendered travel patterns. Information about traveller income also allowed for understanding distinct transport behaviours between groups of women.

However, the dataset also presents limitations for gender analysis. The categorization of non-work travel purposes did not allow for a detailed analysis of care-related travel. For example, the category "shopping" does not differentiate between leisurely shopping and household maintenance purchases. With regards to travel purposes, future data collection efforts can include a distinction between shopping trips and a new category of errands (Ravensbergen et al., 2023), while also including a distinction for traveling with strollers, children (even in trips that are not with the

purpose of accompanying or taking someone to a destination), and groceries. These factors affect women's travel time, the time of day of travel, and modal choice.

A more critical limitation, given the spatial tendency of this thesis, is the insufficient number of observations for a spatially disaggregated analysis of travel destinations between genders. An approximation was explored in Article 2, but ultimately a spatial aggregation to the census tract level was required to have enough observations per unit for statistically robust results. The spatial grid for anonymization of the OD survey is 250 m, a useful spatial resolution to consider detailed land uses, like the presence of care destinations, yet analyses at this scale were not possible due to data sparsity. This meant that the granularity of information about destinations, and hence the distinction between care, groceries, and work purposes, were aggregated into areas too large to be characterized by distinct land uses. Consequently, a research gap that fell within the scope of the thesis, but remains underexplored due to these limitations, is a fine-grained spatial analysis of men's and women's destinations with regards to land use patterns, particularly for non-work travel, and how such insights could inform more responsive transport services. Related to spatial aggregation, Article 3 also required flows to be aggregated to the census tract level, and as a result, communities detected by the method were at a lower spatial resolution. This point will be explored further when reflecting about this methodology.

With respect to spatial aggregation, an ideal solution would be to have a larger dataset; for example, the Toronto Transit Commission (TTC) runs their OD survey data collection for several months to achieve a larger sample size (Ministry of Transportation Ontario, 2023). This introduces temporal variability, but urban and transport conditions typically remain largely stable in this time threshold. As greater data volumes are needed for some analyses, and data collection efforts are costly in time and money, data augmentation alternatives can be explored. For example, depending on the research question and the surveying standards, consecutive iterations of the survey can be used together, controlling for major changes in the transport system. Alternatively, algorithms like iterative proportional fitting (IPF) can be used to increase granularity of sparse data (Tirindelli & Reck, 2026).

The Montréal Segmentation Survey was extremely informative to investigate the relationship between attitudes and socio-economic information. This dataset allowed for unveiling nuances in how women and men think differently about transport systems, to understand factors that affect

their perception, and to realize the need for tailored strategies to promote sustainable modal shifts. Findings suggest that further efforts along these lines should be made in terms of data collection.

However, a limitation of this dataset was the survey's high number of categories for responses, which increases the likelihood of misinterpretation by respondents due to the ambiguous interpretation of categories. Further, the survey allowed respondents to select from many options for different modes reflecting the probability of using a given mode in categorical time spans, they could also lead to ambiguous or imprecise responses. Future data collection efforts can test condensing the set of adjectives used to describe transport modes, and the options available for travel behaviour. Another limitation was that the version of the dataset provided did not contain location information at a sufficient resolution for analysis, therefore hindering the exploration of the relationship between gender, opinions about transport, and land use and transport systems. Future data-sharing agreements could permit the sharing of more detailed spatial information, enabling finer-grained analyses of gendered travel patterns. A last limitation of this dataset is that it only contained information about the mode most frequently used, preventing the assessment of multimodal travel, and it also did not contain detailed trip information, only the aggregated frequencies of the use of modes (weekly, bi-monthly, etc.), relying only on the user's perception of how they travel, more than their actual behaviour.

A final limitation, across all datasets, was that they did not include, or had limited observations, of genders beyond the men/women binary. Literature on the topic has found spatial and geographical constraints, such as immobility and inaccessibility, that non-binary people face when interacting with public transport systems, and highlights the need for more research into non-binary perspectives, patterns, and needs in transportation (Ivanova & O'Hern, 2024). Therefore, the thesis focused on women and men and left unexplored the travel patterns of non-binary individuals and their socio-economic explanatory factors, including caring-related patterns.

Methods

The overarching objective of this thesis was to develop gender-centred analytical approaches to inform equitable transport planning, achieved with a set of articles that performed gender differentiated analyses with an array of methods: linear and multinomial logit regression, factor analysis, spatial indicators of autocorrelation, and spatially-aware clustering. All methods were

effective in highlighting differences between men and women, through all topics explored: travel behaviour, travel dissonance, and transport poverty.

A key and effective approach to finding differences between genders was to perform separate regressions per gender to assess the distinct effect that variables have on the evaluated phenomena. With this approach, all regressions were useful in revealing associated factors with the phenomena, and to understand how they affect men and women differently. However, a limitation of is that causality was not analyzed, nor the underlying mechanisms (whether behavioural or societal) behind these results.

Articles 1 and 2 used Local Indicators of Spatial Association (LISA) to find clusters where men and women experience a transport-related phenomenon with more intensity than the other gender. The limitation of this method is that when it is applied to areal spatial units, in this case small census areas, it is sensitive to the variability of area size (Nelson & Brewer, 2017). Dissemination areas (DAs) and dissemination blocks (DBs) tend to be very small in city cores, and to be larger as they reach rural areas, as they reflect constituent population sizes. Large zones may aggregate heterogenous populations, distorting clustering patterns. However, LISA was useful for identifying nuanced spatial patterns in zones where marginalization, limited accessibility, and a higher concentration of women intersect. In doing so, it highlighted areas of pronounced transport disadvantage for women and pointed to specific locations where transport practitioners can prioritize interventions to improve mobility conditions.

Article 3 used a spatially-aware clustering method, Hierarchical Link Clustering (HLC), to find different patterns in the OD flow pairs of men and women. The method was useful to find that women and men's movement communities are located in different areas of the city. The complementary regression showed that the explanatory factors for the same movement types are different for women than for men, demonstrating that the classification method captures underlying social structures. The link clustering approach used allows a flow to belong to two different communities, which conceptually implies being part of several mobility systems. This approach follows more closely to real life, where a single neighbourhood may simultaneously participate in commuting flows, local activity patterns, and care-related trips, each reflecting different dimensions of mobility. Then, communities detected by this method can transform into multiscale, overlapping functional regions, a perspective that challenges the traditional regionalization of

mobility into separate units (Goetz & Han, 2015; Han & Goetz, 2019). In this sense, the application of this method has the potential to contribute to transport planning theory by offering a relational, flow-based understanding of mobility systems, challenging zone-based regionalization and focusing on the gendered, multi-scalar nature of spatially-aware functional urban regions. This approach has been used before for finding economic functional areas in metropolitan regions (Han & Goetz, 2019) and analysis of taxi movement (Sekulić et al., 2021). This is the first time, to the author's knowledge, that this method is used to understand the flows of different groups of population (gender), emphasizing a human-centred approach to mobility research.

Although the results are insightful, there are some specific key limitations to the spatially-aware clustering method proposed in this thesis. First, due to the lack of data necessary for finer spatial disaggregation (as discussed in the previous section), the analysis had to be aggregated to a much larger spatial unit (census tracts), therefore potentially obscuring fine-grain patterns, like the small trips that women perform for care purposes, and these were instead included in much larger communities of a more heterogenous nature. This limitation may disproportionately affect women's travel. Classification methods tend to thrive with big data, but big mobility data, such as cellphone GPS signals, tends to lack detailed socio-economic information, so a compromise was made for understanding gender differences and explanatory factors. The second limitation was the extent of the analysis; the article focused on developing the method with a gender lens and demonstrating key differences between genders, but a natural extension would be to explore translating overlapping communities into functional units for planning. A final limitation is that the work did not explore the meaning to travellers of belonging to a movement community, what it means for person's experience of mobility, and how these experiential differences can be used in transport planning.

Altogether, a key contribution of the thesis lies in its exploration of a wide array of transport research topics, data, and methods through a gender-centred lens. This breadth allowed for a more holistic understanding of how gender shapes mobility across multiple dimensions of the transport system. Conversely, a limitation of this wide scope is that it inevitably restricted the depth to which any individual topic could be investigated, leaving opportunities for future work to analyze in greater depth each thematic area. Another key contribution of these methods is their flexibility to be adapted to measure different dimensions of equity, upscaled to different geographical contexts,

or combined with one another and other methodologies, reinforcing their utility for transport researchers and practitioners.

CHAPTER 9: CONCLUSION

This chapter presents a detailed account of the limitations (9.1), avenues for future research (9.2), and presents an overview of the thesis in section 9.3.

9.1 Limitations

This thesis advanced gender-centred analytical approaches to understand mobility patterns and transport inequities. As discussed previously, while the analyses revealed meaningful insights, several limitations remain. The main limitations are summarized below.

A central limitation across all datasets was the insufficient spatial granularity required for fine-scale, gender-disaggregated analysis. Although the Montréal Origin-Destination (OD) Survey includes more precise geographic data, the number of observations was too small to support analyses at the 250 m anonymized grid level. As a result, travel destinations and flows had to be aggregated to larger spatial units, such as census tracts. This aggregation inevitably blurred distinctions between land uses, such as childcare, grocery stores, and workplaces, and their relation to mode choice and spatial location. It also obscured short, care-related trips that are more commonly performed by women. The lower spatial resolution also constrained the performance of spatial clustering and flow-based methods, limiting their ability to detect nuanced gendered patterns.

The categorization of travel purposes in the OD survey restricted the analysis of care-related mobility and of women's leisure activities. Further, the absence of indicators such as travelling with children, strollers, or groceries also limited the ability to capture factors that disproportionately shape women's travel time, modal choice, and time-of-day patterns.

The Montréal Segmentation Survey provided valuable attitudinal insights but presented its own constraints. The high number of response categories increased the likelihood of ambiguous or inconsistent interpretations by respondents, while categorical probability scales for mode use may have produced imprecise behavioural estimates. Moreover, the version of the dataset available for this thesis lacked sufficiently detailed spatial information, hindering the ability to relate gendered attitudes to spatial access to transport services.

A transversal limitation across all datasets was the restricted representation of genders beyond the binary. Mostly, these categories numbers were too small to support meaningful quantitative

analysis. This prevented the exploration of mobility patterns, constraints, and care-related behaviours among gender-diverse populations, despite emerging evidence that these groups face distinct accessibility challenges (Ivanova & O'Hern, 2024).

The methodological approaches adopted in this thesis were effective in revealing gender differences across multiple dimensions of mobility, yet they were also shaped by the constraints of the underlying data. Additionally, the methods investigated relations with other factors, but not causality, which could be central for generating effective public policy (Levinson, 2026). The modelling approach of separating models, although effective in showing clear distinctions of directionality and significance of variables between genders, has certain limitations. Gender-separated models reduce the sample size within each group, may lower statistical power, and make it more difficult to formally test whether coefficients differ across groups.

Finally, the thesis adopted a broad thematic scope, spanning travel behaviour, travel dissonance, accessibility, and movement flows, to build a holistic understanding of gendered mobility. While this breadth is a key contribution, it also limited the depth with which each topic could be explored. Several areas identified through the analyses, including the planning implications of overlapping mobility communities and the fine-grained spatial dynamics of care-related travel, warrant more extensive investigation in future work.

9.2 The future of gendered transport research

From the findings and limitations found in this thesis, five main topics emerge as extensions for future research:

1. A detailed, gender-centred spatial exploration of destinations for non-work purposes, at fine spatial resolution, in Canada. This can focus on two main categories: mobility of care and leisure; according to Sanchez de Madriaga (2013), these two categories add up to a similar proportion of trips as work. Results from this exploration can shed light into how women and men use urban services and urban space differently, and help to design policies that better support the needs of women derived from gender roles.
2. Another area for further investigation is the relationship between transport and access to employment opportunities, from a gender lens, and how this manifests spatially. Understanding women's use of public transport for work trips is crucial for achieving equity in transport planning, and ultimately to support women's upward social mobility.

A longitudinal exploration of women's mobility to work can shed light on how changes to transport services affect women's patterns of mobility and immobility when having to balance home and work, and a longitudinal design can take advantage of natural experiments to evaluate causation (Levinson, 2026). Another angle to explore along this avenue is the distribution of time spent between home, work, and care trips, and how this relates to transport service provision, especially with regards to recent changes to mobility and employment (e.g., remote work).

3. Spatially and gender aware movement flow classification can evolve along two complementary directions. First, advancing a more spatially detailed classification of flows, an avenue that was not pursued here due to data limitations, but remains essential for refining the granularity of movement types. Second, a deeper theoretical elaboration of what 'movement types' signify for transport planning, including the development of a structured workflow for identifying functional regions that are sensitive to gendered mobility patterns. Together, these directions would strengthen the conceptual foundations of flow-based regionalization and enhance its relevance for gender-responsive planning practice.
4. This thesis explored gender differences in urban space in Canada, but rural spaces remain underexplored. Access to services in rural areas is highly dependent on personal capabilities and may not be shared equally among groups of residents, as studies in other countries have shown that rural men generally exhibit higher mobility than women (He et al., 2026). This topic would also shed light on how different local contexts influence gender behaviours, even within the larger context of North America. Therefore, an exploration of gender-aware rural mobility would be a necessary contribution to the field.
5. There is also a need for mixed-methods approaches, which can be productive in examining causality, as the mechanisms that lead to differences between women's and men's mobility patterns (at multiple scales, individual, household, community) are often missing from purely quantitative data sources. Qualitative data can supplement to understand how different patterns visible in quantitative data affect people in reality, and the effects of interventions on people's perceived mobility conditions. The contribution of this thesis lies mainly in the demonstration of the applicability of the methodologies to reveal distinct spatial patterns, and the demonstration of gender differences from a multi-

dimensional and multi-perspective approach. However, more efforts are warranted to analyze the different results in terms of their practical significance and implications for planning, policy, and equity.

6. It is worth noting that an important body of knowledge exists regarding the intersectionality of transport phenomena, and that an intersectional perspective can be applied to the topics included in this thesis, through further detailed spatial analyses and investigating under-explored geographies, like rural spaces. Given that gender alone may not fully capture the layered nature of mobility experiences, another useful avenue for exploration, both conceptually and methodologically, can expand on how gender intersects with other social positions, including age, income, race and ethnicity, disability status, household structure, caregiving responsibilities, employment status, etc. to reveal different transport patterns and different transport needs.

Aside from these specific topics, longitudinal studies, and replicating these studies with new data or in different contexts, can be performed in all topics explored. While the broad findings of this thesis in the Canadian context are similar to findings in other contexts regarding women's transport disadvantage, there are few studies that compare women's mobility across geographies. To evaluate the external validity of this work, and the applicability of its methods in different geographies, it would be useful to conduct comparative studies, or to replicate these methods to other cities and countries. Another broad avenue for exploration in both, methods and data collection, is mobility beyond the women/men binary, a topic that can greatly benefit from mixed methods, as they are effective to capture lived experiences.

9.3 Summary

This thesis had the overarching goal of adapting and combining gender-centred analytical approaches to inform equitable transport planning. It achieved it by analyzing three topics across four articles, with an array of datasets and statistical and spatial methodologies. It investigated the ways in which transport, land use, and personal characteristics interact to generate gendered mobility patterns. It found, across topics, that women's transport patterns tend to depend more on socio-economic factors, while men's patterns are explained by transport services, land use, and attitudes. It also found that across topics, peri-central areas are where women's transport disadvantage is located.

For this thesis, data collected by public agencies was used, facilitating the replication of the methodologies, their use in other geographical contexts, and monitoring results by updating with new data. The principal contribution of the thesis is in the methodological development and adaptation of tools capable of showing gender dynamics in transport. At a more conceptual level, the thesis shows, through multiple phenomena and methodologies, that gender is structurally embedded throughout the mobility landscape, reinforcing the need for gender-centred theory and practice.

Article 1 looked at gender differences in transport poverty patterns. Using census data and publicly available spatial access measures, it applied population weighting to the averages of transport poverty and its main components, marginalization and inaccessibility, per metropolitan area. It found that women experience significantly more transport poverty, more marginalization, and less inaccessibility than do men. In this article, Local Indicators of Spatial Autocorrelation (LISA) were used to show spatial nuances in the experience of inaccessibility and marginalization in areas with a high proportion of women.

Article 2 used Montréal's Origin-Destination survey to perform a gendered analysis of distance travelled and destinations. Using a linear regression with bootstrapping, it showed that women travel shorter distances than men for all purposes, that the presence of children in the household affects women's distance more than men's, and that monoparental and middle-income households show a smaller gender gap. Then, it used LISA to explore the areas where men and women travel more to, for different purposes. It found that women travel more to suburban areas for work, care trips, and leisure, while men travel more to central areas for these purposes.

Article 3 performed a spatially-aware gender classification of mobility flows using Montréal's Origin-Destination survey. With a Hierarchical Link Clustering (HLC) algorithm, it classified OD flows into movement types and then performed a regression to understand the factors that explain these movement types. It found that women's flows tend to be classified as local-based and mixed-elongated. It also found that movement types describe different patterns in the city between genders, especially the mixed-elongated type, where women move more in the pericentral north area of the island. Finally, the regression found that women's communities are affected by socio-economic factors, while men's communities are explained more by land use and transport.

Article 4 explored gender differences in attitudes towards transport modes and their relation to travel dissonance. It used the Montréal Segmentation survey and performed a factor analysis and a multinomial logit regression to understand the factors that explain dissonance per gender. The factor analysis revealed that women place a similar importance on affective constructs as on transport efficiency in choosing a mode, while men place more importance on transport efficiency factors alone. It also discovered that women have a nuanced opinion about particular transport modes, while men's opinions tend to be more positive with respect to the assessed modes, except for the bus. Finally, it found that women's dissonance is explained more by socio-economic factors, while men's is more explained by their attitudes and opinions.

Together, the four articles demonstrate how gender shapes mobility across behavioural, attitudinal, and spatial dimensions, and how public data can be studied to reveal these dynamics. The consistency of the findings across different topics underscores the structural nature of transport inequities related to gender, and the need to incorporate gender-centred approaches in transport research, policy, and practice.

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APPENDIX A: DEVELOPING A COUNTRY-WIDE INDEX FOR MEASURING TRANSPORT POVERTY: METHODS AND INSIGHTS FROM CANADA

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to *Sustainable Transport and Livability*

Introduction

In the context of climate change, sustainable transport is receiving increasing interest to reduce greenhouse gas emissions and improve livability in fast-growing urban areas. A key dimension of sustainable transport, which has typically received less attention, is the social dimension. Transport plays a crucial role enabling individuals' participation in society, especially in car-oriented areas, where without a car access can be severely limited. In recent years, researchers have coined the term transport poverty, referring to the lack of adequate transport options to reach opportunities to satisfy an individual's daily basic needs (inspired from Lucas et al. (2016)), to address this gap. Transport poverty focuses on the interactions between transport (and often land use) and social conditions that prevent individuals from reaching opportunities to meet their daily basic needs, which in turn, can lead to transport-related social exclusion. Transport poverty is, therefore, of special interest for transport practitioners involved in decision-making processes with a focus on equity in the distribution of transport services.

As transport is increasingly seen as a key component of equitable and sustainable communities, it is also receiving attention from higher levels of government. In Canada, there are two funds being promoted from the federal government to local levels of administration for supporting sustainable transport investments: the Public Transit Fund (Canada, 2018) and the Active Transport Fund (Canada, 2021). Both are oriented towards improving the population's access to opportunities, through financing interventions in planning, infrastructure, or services. In Europe, the European

Union has the 2020 Sustainable and Smart Mobility Strategy (European Commission, 2020) that sets strategies and milestones until 2050 around sustainable transport. As transport poverty investigates the relation between land use and transport, and social processes, it is a suitable vehicle to guide public investments in ensuring equity between populations, while supporting the development of sustainable transport systems.

Transport poverty is often measured at the local scale of analysis, such as for a particular city (Iqbal et al., 2020; Lunke, 2022; Martens, 2013). While much has been learnt from these analyses, to date there have been fewer studies that measure transport poverty at a national scale of analysis, and none has done so in large and geographically diverse countries/regions such as Canada or the U.S. Therefore, there is a need to design, implement, and adapt existing methodologies for studying transport poverty to account for large, diverse territories. By making it possible to compare different parts of the country, this can support planning processes by guiding transport-related investments, benchmarking the attainment of equity goals over time nationally, assessing how investments affect related indicators after implementation, or identifying factors that successfully lead to lower levels of transport poverty. A national study of transport poverty could also be used to compare equity across the country, providing a useful methodology for cities to understand their transport systems, and to develop better services to reduce transport poverty.

Measuring transport poverty across a country poses several challenges, from the conceptual to the operational ones. On the conceptual side, a country's territory is naturally dissimilar: different concentrations of populations and different activities and ways of life denote the need for multiple visions, or at least different assessments or views, of the same problem. Operationally, the various standards of data gathering that local administrations employ make it difficult to measure and evaluate a problem in a standardized manner, at a large scale. These are expected challenges in measuring transport outcomes at national scale (Li et al., 2011; Verhorst et al., 2023). In Canada, provincial governments have substantial autonomy in designing their information gathering schemes, varying both in periodicity and the detail of the information. One of the few exceptions is the population census, conducted every five years at the national level. Additionally, national transport networks and datasets have been recently developed and made publicly available by Statistics Canada (2023).

To respond to the lack of studies considering transport poverty at the national scale of analysis, this contribution has three objectives:

1. To propose a methodology to measure transport poverty for all of Canada, that can at the same time be used to make comparisons between areas in the country, and within local boundaries for planning purposes.
2. To assess the challenges of creating an easily interpretable methodology for assessing transport poverty, to help guide transport-related decision-making across geographical contexts.
3. To demonstrate potential uses of the methodology.

The remainder of this paper explains the methodological process and the possible applications and policy-related implications of the methodology. These applications are demonstrative, rather than serving as a diagnostic portrait of Canada; in this light, the discussion is oriented towards assessing the method.

Literature Review

Transport poverty: A multidimensional concept

Transport poverty can be understood as the joint effect of social (low income, chronic illness, etc.) and transport (no car, poor public transport access, etc.) disadvantages (Lucas, 2012; Nakshi et al., 2025). More specifically, Dorantes and Murauskaite-Bull (2023), in a recent review of transport poverty, take the perspective of transport poverty as a lack of sufficient transport alternatives resulting from individual and land use and transport factors. As such, different factors may lead to transport poverty: financial (e.g., inhibiting the purchase of a car or public transport tickets), mental or physical abilities (e.g., a person may not be able to use a public transport service because of a travel-related impairment, or a fear of being harassed in transport), or, a lack of available services (Luz & Portugal, 2021).

There is strong evidence that significant barriers to participation in key activities (e.g., employment, education, health, and social) can be due to a lack of suitable transport options, a lack of accessible opportunities, or a combination of both (Kamruzzaman et al., 2016). To encompass the full complexity of lack of access to opportunities, Lucas (2012) also considers the socio-economic conditions of the individual, pointing out that transport disadvantage and social disadvantage interact directly and indirectly to cause transport poverty. The interplay of these

factors demonstrates the multidimensional nature of transport poverty, and, therefore, the need for developing frameworks that can incorporate the variety of factors. With this, transport poverty can be understood as an individual suffering from at least one of the following conditions: no transport option available that suits their needs; the existing options do not reach destinations that satisfy their daily activities; the weekly amount spent on transport is above the official poverty line; travel times are overly long; or travel conditions are unsafe, dangerous, or unhealthy (Lucas et al., 2016; Pérez-Peña et al., 2021).

Drawing from the concept of transport poverty, it can be concluded that an individual suffering transport poverty is at risk of not being able to access opportunities and participate in society, and is therefore at risk of suffering transport-related social exclusion (Lucas, 2019; Luz & Portugal, 2021). Therefore, there is a special interest in studying the relationship between transport and individuals' socio-economic conditions. From the many definitions of transport poverty, most are composed of at least one economic component and one component related either to transport or land use. The transport component of transport poverty is often a measure of "transport disadvantage", but some studies (e.g., Allen & Farber, 2019) have suggested using accessibility for this transport component, as it captures the interactions between transport and land use.

In this study, we use the conceptual framework presented in **Figure A.1**, largely inspired from Lucas (2012), but replacing the transport disadvantage component with an accessibility disadvantage component. Accessibility is used because what matters is access (Pereira et al., 2017), understood as the interaction between transport and land use, instead of transport alone, since the transport options available depend on the location of destinations that need to be accessed. As such, a large body of research has shown that accessibility to destinations by active and public transport is closely linked with travel behaviour transport-related social exclusion outcomes (Luz et al., 2025). Additionally, the socio-economic disadvantage is characterized by both individual and household conditions, as these are key factors individuals' access to destinations (Lucas, 2012; Awaworyi Churchill & Smyth, 2019; Ettema et al., 2025). In this conceptualization, transport poverty occurs at the intersection of socio-economic, and transport and land use disadvantages. Then, transport poverty leads to a lack of access to goods and services and can result in transport-related social exclusion. Building on Lucas' (2012) framework, we specifically define transport poverty as the joint effect of transport and social disadvantages that lead to a lack of access to opportunities, and in turn, social exclusion.

It is worth clarifying the terms employed in this study. In our framework, the term transport disadvantage (expanded to include the land use component) strictly refers to transport conditions. In other cases, transport disadvantage reflects broader transport-related negative outcomes. For example, Schwanen et al. (2015) define transport disadvantage as an "outcome of a lack of access to basic resources, activities and opportunities for interactions, of a lack of cognitive knowledge, know-how, aspirations and/or autonomy regarding travel and its externalities, and of a lack of influence on decision-making in the context of transport policy and governance". This broader definition of transport disadvantage is more closely related to our working definition of transport poverty. However, whereas the transport disadvantage definition proposed by Schwanen et al. (2015) focuses more directly on the transport-related outcomes (for example, lack of influence on transport-related decision-making processes, and exposure to negative transport externalities), the working definition of transport poverty employed in this study emphasizes the broader social exclusion that can result from it, and, later on, Ravensbergen & Schwanen (2025) also use the transport poverty definition.

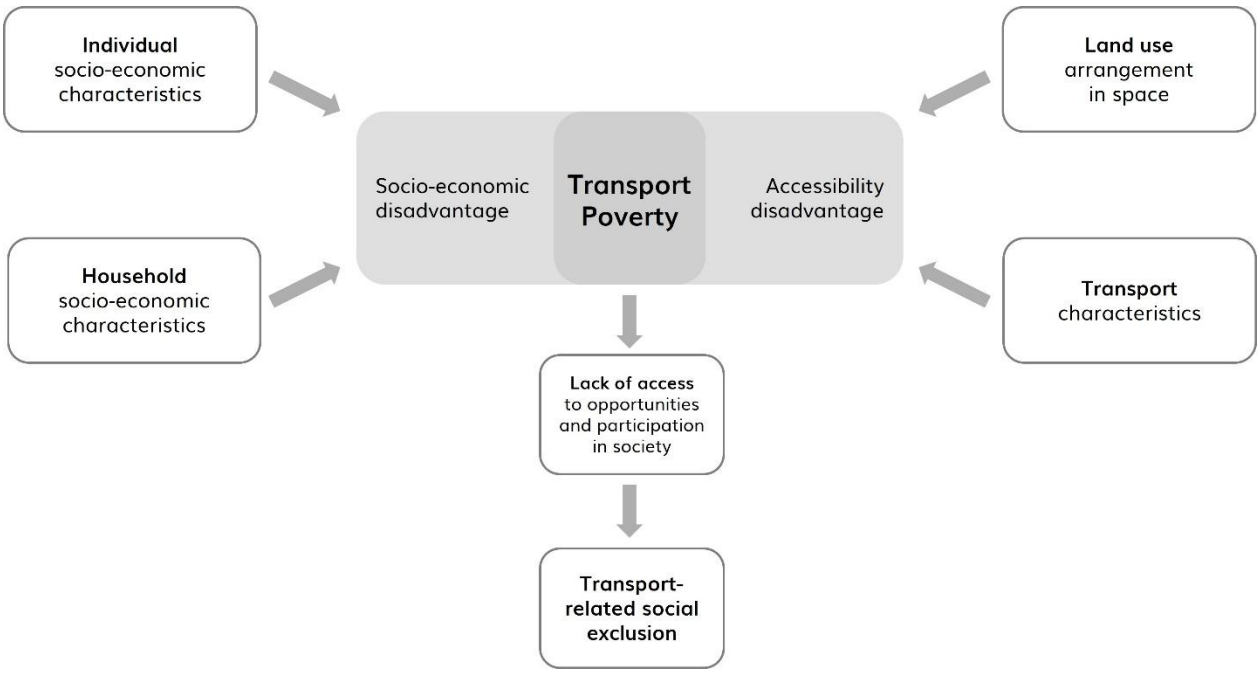

Figure A.1 Conceptual framework, adapted from Lucas (2012).

Methodologies for measuring and analyzing transport poverty

There are multiple approaches to measuring transport poverty at the individual, household, or regional scales. Some studies contemplate single city case studies or a comparison between two cities. Given that transport poverty is still a concept under development, and that it is multidimensional (time, affordability, availability, capabilities, etc.), Verhorst et al. (2023) systematically review the literature to obtain different definitions of transport poverty. They then use survey data from two Dutch cities to measure transport poverty to understand which transport poverty definition correlates with different sets of predictors. The results indicate that different sets of predictors become more or less relevant depending on the definitions, and depending on if the measurement is done at personal, household, region, or city scale. They conclude that when evaluating transport poverty, a combination of objective measurements and subjective perceptions should be considered for a more extensive insight into the state of transport poverty. Ettema et al. (2025) study subjective self-reported measures of accessibility to account for travellers' perceptions of limitations in the transport system, using data from Utrecht and Rotterdam, with a sample focused on socially vulnerable populations. The questionnaire evaluates the adequacy of the transport system through affirmations about travel options/limitations, travel experiences, and

access to destinations and life outcomes, measured by agreement with a five-point Likert scale. Mean transport adequacy scores were calculated to reflect factors commonly associated with transport poverty. Descriptive and regression analyses found that transport adequacy was lower for those with lower incomes, no car access, and those using mobility aids.

Some national analyses also exist. Berry et al. (2016) study transport poverty nationally in France, and focus on fuel affordability by identifying households vulnerable to fuel price increases. The authors design a composite indicator that measures financial resources (income), mobility practices (fuel spending, travel time, etc.), and conditions of mobility (spatial matching), though the study was limited to commuting trips. In a regional analysis, another article makes a comparison between Sydney and Perth, Australia, with a transport supply index, using the Lorenz Curve and Gini Index to compare the transport service distribution under different socio-economic characteristics, including housing affordability, employment self-sufficiency, urban sprawl, and transport mode (Xia et al., 2016). In the Canadian context, Allen and Farber (2019) examine access to employment from a vertical equity perspective, understood as the distribution of a resource for specific, often vulnerable, groups in eight Canadian cities. Using open public transport network data, accessibility measures, household demographics, and employment census data, they estimate the risk of transport poverty. Access to jobs was measured for different income levels, to analyze mismatches between job types and workers' socio-economic conditions. This analysis works towards the national scale, by considering the most populous cities, but does not include intermediate and small cities and rural territories.

All methods present different advantages and disadvantages depending on the purpose of the study. However, an overarching disadvantage of most of the studies is not the methods themselves, but that they are limited to local or regional scales. The amount and detail of data needed for these approaches (GTFS, travel times, disaggregated travel costs, types of destinations, etc.) cannot be guaranteed to be available when scaling to the national scale or making comparisons between regions or nations. It thereby limits the possibility of identifying challenges and opportunities that arise when assessing transport poverty at the national level. One exception is the comprehensive regional scale analysis of transport-related social exclusion found in the Transport for The North (2022) project, which uses the English Indexes of Multiple Deprivation (IMD) and an accessibility score that examines the relative and absolute level of access to employment, education, healthcare, transport resources, and basic services to create a combined classification of both scores that allows

them to estimate the risk of suffering from transport-related social exclusion in the North of England.

Transport poverty is a broad concept that involves many dimensions and is still being developed; therefore, there are a variety of ways to measure it. Looking across this research, most studies have been based in a city, or a few cities, and there are fewer studies at the national level, with the Transport for The North (2022) study being among the most comprehensive. This represents a gap in the literature, as national-level analyses would provide policymakers with information about transport poverty that can be compared across the country. While the regional analysis in the UK from Transport for The North provides a good starting point, their methodology is not directly applicable to countries as geographically diverse as Canada, as there is no method accounting for the measure working across very different territorial fabrics and governance entities. This means that the interaction between urban and rural areas, and the differences between big and small agglomerations, are less present in transport poverty studies. This paper responds to this research gap by presenting a methodology to measure transport poverty at the national level, which can also be applied to other large, car dependent, and geographically diverse countries.

Methodology

Building on the work by Transport for The North (2022) for measuring transport poverty at the national level, we create a methodology (presented in **Figure A.2**) with two indexes of transport poverty, each composed of two sub-indexes. The two sub-indexes are a socio-economic component and a land use and transport component, which are explained in section 3.1 and 3.2 respectively. The two indexes of transport poverty are a composite continuous index of transport poverty (between 0 and 1) and a categorical ranking of transport poverty (five levels), and will be explained in section 3.4. The reason for two outputs was to make the methodology flexible and informative for different research and decision-making spaces, and will also be explained more in detail in 3.4.

Several challenges emerged when measuring both socio-economic and land use and transport factors nationwide, considering the heterogeneity of the territory. The first challenge was data: what types of data sources are available for the entire country, and will they be updated to facilitate future periodic analyses? A second challenge was how to understand a phenomenon (transport poverty) that materializes in unique ways across different geographies; for example, urban vs. rural areas, small agglomerations vs. metropolitan areas, etc. The third challenge was more analytical:

once a nationwide geographically disaggregated index is available, how do you start processing and understanding such a large volume of data? And what are the possible applications of this methodology?

To respond to the first challenge, we used Canadian Census and Spatial Accessibility Measures (Statistics Canada, 2023) data, because it is consistently applied across Canada and periodically updated by a single entity. We explored the second challenge by rescaling the indexes at different geographic scales, producing a methodology that can be equally informative and readable at national, regional, or local scales, when the geographies can be very different and contrasting from one another. For the third challenge, we propose an analytical approach, of gaining insight on variations of transport poverty across scales, and, how social and transport disadvantage interact to shape transport poverty, as a first attempt to understand the situation of transport poverty, leaving room for other flexible applications. All statistical analyses were performed in R (Posit Team, 2025), and geographical operations in QGIS (QGIS.org, 2022).

This proposal takes from Kelly et al. (2023), who create a composite index of transport poverty risk to capture the complexity and diversity of mobility contexts. The authors demonstrate that these measures should be designed considering socio-economic characteristics, the locations of different types of daily activities, and land use and transport supply to achieve a more complete view of transport poverty. In this line, **Figure A.1.2** summarizes the methodology, with all steps that led to the creation of the two indexes of transport poverty. First, there is a process of measuring the socio-economic (marginalization) and the land use and transport components (inaccessibility), by calculating sub-indexes, both fed by secondary data sources. Then, there is a step of spatial matching to transfer both sub-indexes to the same spatial unit. The following step is to scale both sub-indexes to three different spatial scales: *national, metropolitan and municipality/county scales*. Finally, both sub-indexes are combined, to obtain two synthetic indexes of transport poverty with a continuous index (TRPOV) and a categorical classification (TRPOV-R) as results. The remaining portion of this section will explain each of these steps in detail. The main data sources are indicated in **Figure A.2**, with the full list of variables presented in Appendix B.

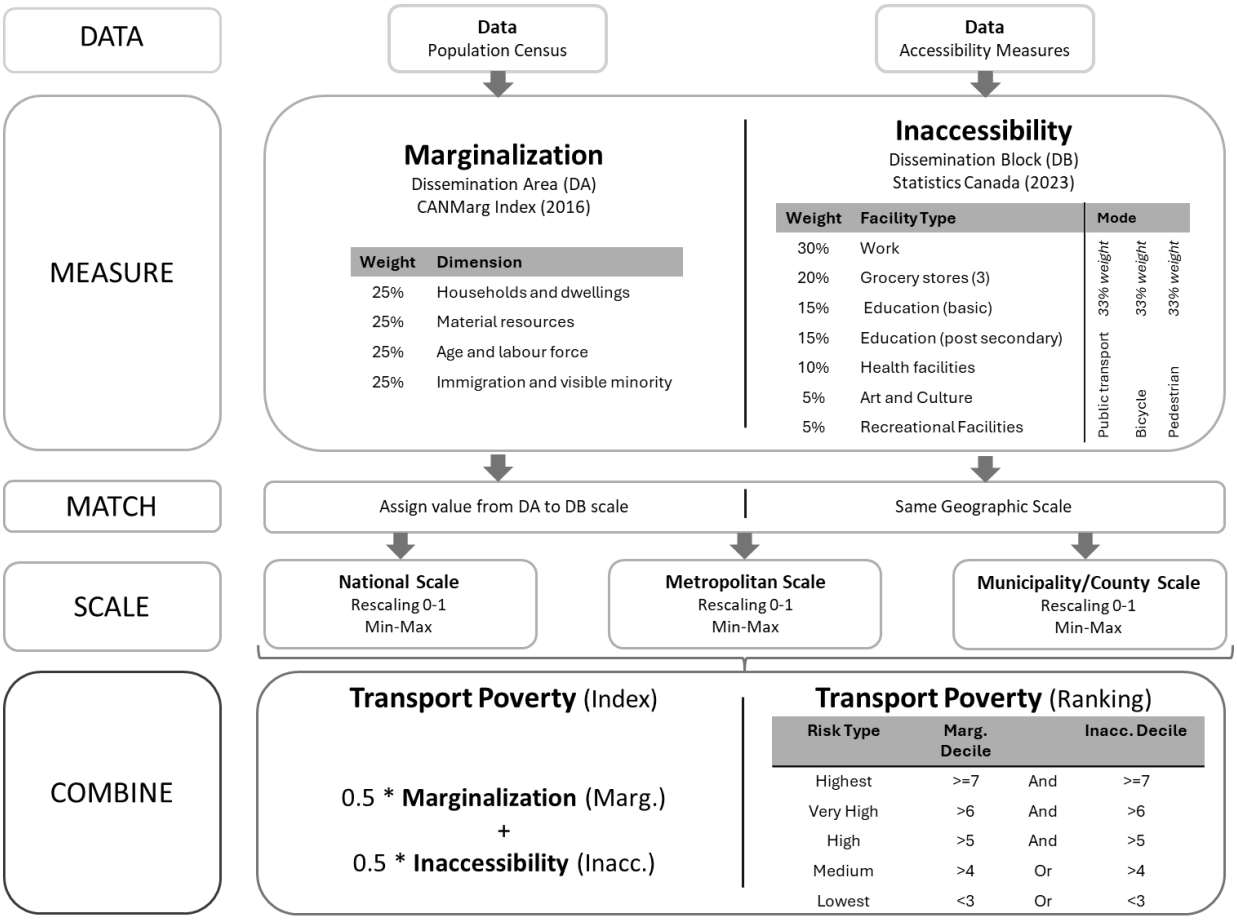

Figure A.2 Methodology for measuring transport poverty at the national scale.

Socio-economic component: Marginalization sub-index

Related work has used indicators of multiple deprivation with variables of income, employment, education (Primc et al., 2025; Transport for the North, 2022), health, crime, wider barriers and outdoors living environment (Transport for the North, 2022) to determine social disadvantage in transport poverty. This type of composite indicators allows capturing a wide array of personal characteristics that describe vulnerability, and have been related to transport outcomes in past studies (Cui et al., 2020). In a similar vein, this work uses a Canadian indicator of multiple deprivation for the socio-economic sub-index, that was created by Matheson et al. (2012). This index was developed using previous work on deprivation and marginalization, and empirically derived using principal components factor analysis, and has been proven stable in different iterations of the census. The index has been associated with the distribution of inequitable health outcomes as hypertension, diabetes, etc. (Matheson et al., 2012). It measures marginalization using Census data at the Dissemination Area (DA) level and comprises four socio-economic dimensions:

households and dwellings, material resources, age and labour force, and immigration and visible minority. Following Matheson et al. (2012)'s approach and using the 2016 census data, for each dimension, a number of variables were included (see **Table A.1**), and these variables were treated as averages or proportions of the population. The four components were scaled from 0 to 1, and then combined in a synthetic sub-index with equal weights for all dimensions.

Table A.1: Dimensions and variables of the marginalization sub-index (from Matheson et al. (2012)).

Households and Dwellings	Proportion of the population living alone
	Proportion of the population who are not youth (ages 5-15)
	Average number of persons per dwelling
	Proportion of dwellings that are apartments in a building with 5 or more stories
	Proportion of the population who are single/divorced/widowed
	Proportion of dwellings that are not owned
	Proportion of the population who moved during the past 5 years
Age and Labour Force	Proportion of the population who are aged 65+
	Dependency ratio (total population 0-14 and 65+/ total population 15 to 64)
	Proportion of the population not participating in labour force (aged 15+)
Material Resources	Proportion of the population aged 15+ without a high-school diploma
	Proportion of families who are lone parent families
	Proportion of total income from government transfer payments for population aged 15+
	Proportion of the population aged 15+ who are unemployed
	Average after-tax income for population aged 15+
Immigration and Visible Minority	Proportion of the population who are recent immigrants (arrived in the past 5 years)
	Proportion of the population who self-identify as a visible minority

Land use and transport component: Inaccessibility sub-index

The land use and transport component is based on an inaccessibility sub-index, derived from accessibility measures provided by Statistics Canada (2023). The measures in question compute the ease of reaching destinations using gravity-based models for three modes of transport: public transport (peak and off-peak), cycling, and walking (Statistics Canada, 2021a). The gravity model used by Statistics Canada builds on the methods developed in Alasia et al. (2017). Mathematically, the attractiveness of a destination point j from an origin point i is proportional to the amenity mass m at j weighted by the function f of the travel duration d between i and j. In this case, the amenity mass is equal to 1 for all destinations. The access level A of an origin point i is the summation of the destination attractiveness of all destinations J (**Equation A.1**). The distance function (Equation

A.2) parameter λ is assigned as 15 minutes for public transport and cycling and 10 minutes by walking.

Equation A.1:

$$A_i = \sum_{j \in J} f(d_{i,j}) * m_j$$

Where

Equation A.2:

$$f(d_{(i,j)}) = 1 - \left(1e^{\left(-\frac{d_{(i,j)}}{\lambda}\right)}\right)$$

The measures were updated and released in 2023, though the documentation is from 2021. These measures were calculated at the Dissemination Block (DB) level for the 2021 Census geography for 498,547 census blocks. Diverse types of destinations were included, namely: cultural and arts, health, educational, post-secondary educational, and recreational facilities; employment; and groceries. As for the exclusion of private cars, though access to a car is common in Canada, it is by no means universal, especially amongst marginalized groups, and it has been shown that a greater proportion of people in the low-income group use public transport as their main mode of commuting in Canadian CMAs (Cui et al., 2020). Hence, from an equity perspective, where one of the main goals is a redistribution of services, public transport systems tend to have a greater impact on the lives of more vulnerable groups. Similarly, providing access by active transport can reduce the barriers associated with car ownership and car use, while supporting sustainable travel.

In the case of public transport, off-peak accessibility values were used so that the measure would reflect worst-case scenarios, and because disadvantaged population groups (women, elderly, low-income, etc.) tend to travel more during off-peak hours (S. Zhang et al., 2021). For public transport trips, the accessibility measures provided by Statistics Canada used r5r and GTFS data (Pereira et al., 2021) with a commuting duration threshold of 90-minutes, a default walking speed of 3.6 km/hr, and a max walking distance from and to public transport stops of 1000-meter as assumed parameters. Other details, like road hierarchy, for public transport, is handled by the r5r package which employs OSM's road classification based on a function where motorways are highest in the hierarchy, because they move high volumes of vehicles at high speeds, whereas residential roads

are lowest in this hierarchy, because they typically provide access to housing without connecting neighbourhoods. For cycling, cycleway and bicycle tags from OSM were used as higher priority for routing this mode (Statistics Canada, 2024).

All measures, calculated based on the gravity-based measures, had a score scaled from 0-1 for all DBs with one exception: accessibility to groceries. This was measured as accessibility to the first three grocery stores, to better indicate access to proper nutrition options, rather than measuring accessibility only to the nearest grocery store (the first store can have very limited food options). Because this resulted in a measure showing the minimum time it takes to reach the first three facilities in minutes, it was scaled from 0-1, and then subtracted from 1 to obtain a measure in the same direction and scale of the others (all other measures were a score of accessibility, where 1 means better conditions, whereas with a time measure, larger numbers mean longer times, implying less desirable conditions). Because this resulted in a measure showing the minimum time it takes to reach the first three facilities in minutes, it was scaled from 0-1 using **Equation A.3** (where t corresponds to the travel time), and then subtracted from 1 to obtain a measure in the same direction and scale of the others (all other measures were a score of accessibility, where 1 means better conditions, whereas with a time measure, larger numbers mean longer times, implying less desirable conditions).

Equation A.3:

$$A_{i,scaled} = \frac{t_i - t_{min}}{t_{max} - t_{min}}$$

Then, for each type of destination (*D*), the scores for all modes were combined with equal weights to obtain a combined score, again between 0 and 1, as follows:

Equation A.4:

$$A_{i,D} = 1/3 * \mathrm{A}_{i,D,car} + 1/3 * \mathrm{A}_{i,D,cycling} 1/3 * \mathrm{A}_{i,D,pedestrian}$$

Finally, the combined scores were aggregated with specific weights for each destination (see **Figure A.2 and Equation A.5**) to obtain a final accessibility score $A_{i,score}$ for each origin point. The weights were initially based on the proposal of Zheng et al. (2019), whose study weighs activity types according to their relative importance to quality of life. We then adapted the weights to the Canadian context by consulting the Mobilizing Justice team, experts in transport accessibility

in Canada. We maintain the same hierarchy of weights for the available categories of destinations as in Zheng et al. (2019), and adjust the number for a scale of 0-1. **Figure A.2** has the final weights used for the different categories of destinations with a total of 1, but weights can be adjusted according to study purpose and context in future applications of this methodology.

Equation A.5:

$$A_{i,score} = 0.3 * \mathrm{A}_{work} + 0.2 * \mathrm{A}_{groceries} + 0.15 * \mathrm{A}_{educ.postsec.} + 0.15 * \mathrm{A}_{educ.basic} \\ +0.1 * \mathrm{A}_{health} + 0.05 * \mathrm{A}_{art} + 0.05 * \mathrm{A}_{recreation}$$

As the marginalization index also ranges from 0-1, but with 1 representing the most marginalized areas, the accessibility score was subtracted from 1 to obtain two sub-indexes in the same direction. This subtracted accessibility measure is termed *Inaccessibility*.

Matching different geographies

Since the marginalization and inaccessibility sub-indexes were calculated for different geographic scales (DA and DB respectively), and for geographic boundaries of different years, all measures of the marginalization sub-index were transferred to the smallest and more updated geography, 2021 DBs, to retain precision. Since marginalization dimensions represent percentages of the population, they were assigned to smaller geographies using spatial joins.

Combining indexes

Transport Poverty index (TRPOV)

To obtain a measure of transport poverty, both the socio-economic (*marginalization*) and *inaccessibility* sub-indexes were combined with a weight of 0.5 each, obtaining a synthetic continuous measure from 0-1. These weights can also be adjusted according to purpose.

A process of validation of the weights of the sub-indexes was conducted, testing weights of 0.25-0.75, 0.4-0.6, 0.5-0.5, 0.6-0.4 and 0.75-0.25 for each. When the weights of the marginalization sub-index were above 0.5, the TRPOV index was left-skewed, implying very low transport poverty. When inaccessibility was assigned weights above 0.5, the data was very right-skewed, indicating extreme transport poverty, while a weight of 0.5 for each managed to balance the effects of both. While further sensitivity analyses are warranted, we opted here for the 0.5-0.5 weight as it provided the more balanced index. This means that it better highlighted the differences in terms of transport

poverty at the national level, though it may not necessarily more closely reflect lived experiences; this presents an opportunity for future research. A mathematical sensitivity test of the weights was made using the Main Effects method proposed by Paruolo et al. (2013), which finds values of 0.55 for Marginalization and 0.45 for Inaccessibility. These values are close to an even 0.5-0.5 weighting scheme, and since we currently lack on-the-ground validation of the TRPOV measures with lived experiences, we continue with the 0.5 weighting for each indicator, as a demonstration of the utility of this method. Future analyses can supplement this method with validation, allowing also for weighting selection tailored to study purpose

Transport Poverty Ranking (TRPOV-R)

The transport poverty continuous index can obscure the real situation of certain geographies when dealing with extreme values. For example, in the most extreme case, a score of 1 in one component and 0 in the other would have a transport poverty index of 0.5. Yet, in reality, whoever is at the lower extreme in either of the components is in a less vulnerable position, as they have either socio-economic or accessibility advantages. In addition, a fully continuous measure might be overly abstract when communicating or interpreting results. As such, the interpretation of the measure depends on the distribution of the data: for example, a value of 0.7 may represent a low transport poverty if the mean is 0.8. Conversely, if the mean is 0.3, this may reflect a high transport poverty. Similarly, the continuous values do not directly provide information on potential thresholds or target values that could support decision-making.

Instead, a categorical variable might provide a more intuitive understanding of the situation and a more theoretically grounded interpretation. For these reasons, we develop a categorical classification, based on the marginalization and inaccessibility sub-indexes. The idea is to identify areas that combine high levels of both marginalization and inaccessibility, since a combination of both have been shown to lead to higher risks of transport poverty. While we acknowledge that transport poverty is an individual condition, it is assumed that areas with high levels of marginalization and inaccessibility are more likely to have a concentration of individuals in a situation of transport poverty. Therefore, this classification enables identifying areas that may require transport interventions. Based on the work of Transport for The North (2022), categories were assigned according to the deciles of each component (marginalization and inaccessibility) following a set of classification rules (**Figure A.2**). These rules assign each geographic unit a

category of Low, Medium, High, Very High, or Highest TRPOV-R. In general, if in any DB either marginalization or inaccessibility are in the lowest five deciles (between 1 and 5 inclusively, meaning low marginalization or low inaccessibility), determined by percentile cutoffs, they are considered to be in the medium or low category of transport poverty. This classification implies that either by socio-economic resources or favourable land use and transport characteristics, individuals is these areas are less likely to be transport poor. With this same reasoning, a simultaneity of both high values of marginalization and inaccessibility result in a high level of transport poverty. The ranking is conducted after the rescaling of the Inaccessibility and Marginalization sub-indexes (see **Figure A.2** and section **Different geographic scales** that follows). Accordingly, the ranking is relative to all other DBs in the area under investigation (whether it is the whole country, the metropolitan area or the municipality/county).

Different geographic scales

Canada, like many other countries and regions, has a diverse territory, featuring very concentrated metropolitan urban areas, smaller urban agglomerations, and large portions of rural land. Therefore, a single measure or classification with all geographic units can be inaccurate or of limited use, due to the effect of areas with extreme characteristics (for example, large metropolitan regions vs. isolated villages). Furthermore, land use and transport, as well as socio-economic policies, are regulated at different jurisdiction levels, ranging from the national to the provincial, regional, municipal, and borough levels. Consequently, it is necessary to be able to calculate the measure at different scales of analysis.

By default, and as described above, the sub-indexes and transport poverty indexes were first calculated for the whole of Canada (with DB as the unit of analysis), referred to as the *national scale* (See **Figure A.3**). This scale of analysis includes all areas in Canada. Yet, for local administrators, a more local depiction of their reality is more useful than a single national scale.

To face this challenge, the results were also calculated at the *metropolitan scale*. To do so, a rescaling of all measures was made by grouping DBs based on the Census Metropolitan Areas (CMA) or the Census Agglomerations (CA) to which they belong. The CMAs and CAs represent the urban areas of the country and contain most of the country's population. By definition, CMAs/CAs are formed by one or more adjacent municipalities centred around a population centre; CMAs must have a core of a minimum of 100,000 inhabitants and CAs, 10,000 (Statistics Canada,

2016b). As of 2021, 73.3% of Canadians live in urban centres of 100,000 or more people, and 9.2% in urban centres of 10,000 or more people (Statistics Canada, 2022). Accordingly, this scale of analysis encompasses 81.5% of the national population. For each metropolitan region (CMA or CA), the original marginalization and inaccessibility were rescaled and assigned a value between 0 and 1 using the min-max scaling approach, with the formula in **Equation A.6**:

Equation A.6:

$$X_{scaled} = \frac{\mathrm{X}-\mathrm{Xmin}}{\mathrm{Xmax}-\mathrm{Xmin}}$$

Additionally, because CMA/CAs do not encompass the totality of the territory and population, another rescaling was made by Census Division (CD), following the same procedure. This corresponds to the *municipality/county scale*: CDs are a group of neighbouring municipalities, joined together for the purpose of regional planning and managing common services (Statistics Canada, 2016a). As is the case for the CMAs and CAs, CDs are composed of a group of DBs, allowing a direct spatial match. Compared to the *metropolitan scale*, which excludes rural areas, this *municipality/county scale* considers the state of rural areas by including all DBs in the country, but considers a local scale in comparison with the *national scale*. It is worth noting that since classification is relative to the chosen geography, results are not directly comparable across scales.

Results

Once the TRPOV continuous index and TRPOV-R categorical classification are calculated for the three different geographic scales, there are extensive possibilities for analysis. In this section, we present how the methodology developed using nation-wide data and calculated at different scales can be used to inform researchers and policymakers about the state of transport poverty across a territory. To frame the analysis, we specifically investigate the following questions:

- How do results vary across geographic scales?
- How do marginalization and inaccessibility interact and shape transport poverty in urban areas in Canada?

How do results vary across geographic scales?

In this section, we explore one of the main features of the indexes we developed: the importance of geographic scale when looking at nationwide data, a feature that gives the methodology

flexibility in interpretation and adaptability to different realities in the same country, and to different needs in terms of research and planning.

Figure A.3 shows the differences between the three geographical rescaled indexes of both TRPOV (categorized by deciles) and TRPOV-R. This analysis uses the Montréal Island as an example. The Montréal Island corresponds to a Census Division (CD), located in the Montréal metropolitan region (CMA). The measures can thus be calculated and analyzed at: (i) the *national scale* (**Figures A.3a** and **A.3d**), which considers all DBs in Canada, (ii) the *metropolitan scale* (**Figures A.3b** and **A.3e**), which includes all DBs located in the Montréal metropolitan region, and (iii) the *municipality* scale (**Figures A.3c** and **A.3f**), which includes only the DBs on the Island of Montréal. On all maps, gray areas represent empty values, whether because the census was not applied (national parks, for example), or because they do not belong to the area under analysis (Canada, Montréal metropolitan region or Montréal Island).

The *national-scale* TRPOV map (**Figure A.3a**) shows most of the poverty concentrated in the rural areas (in the periphery), whereas large areas of the Montréal metropolitan region are in the lowest deciles of TRPOV. In contrast, the *metropolitan-scale* map shows only a small core with low transport poverty on the Montréal Island, the rest of the metropolitan region being mostly transport poor areas (**Figure A.3b**). The *municipality/county-scale* picture (**Figure A.3c**) displays a more nuanced reality, with more local variations, closer to the local reality on the ground.

Similarly, when exploring the results for the TRPOV-R, the *national* picture (**Figure A.3d**) shows that almost all DBs on the Montréal Island are in the low and medium categories, whereas the highest categories are in the rural areas. In the *metropolitan* scaling (**Figure A.3e**), it is hard to distinguish patterns of transport poor areas; the areas with the highest levels are dispersed across the territory. Notably, some clusters on the Montréal Island now fall into the three highest categories. Finally, at the *municipality scale* (**Figure A.3f**), there are more clusters of both extremes of TRPOV-R (low and highest) on the Island, providing a more fined-grained diagnosis, potentially more relevant for local authorities.

It is important to note that we see important differences between the TRPOV (**Figures A.3a, b,** and **c**) and TRPOV-R (**Figures A.3d, e,** and **f**) indexes, especially at the larger geographic scales (*national* and *metropolitan*). One possible explanation is that the larger scales might obscure some disadvantages in terms of inaccessibility when comparing the Island (higher density areas with

extensive public transport systems) with rural areas (low density areas with limited mixed use and public transport services). Since the TRPOV-R excludes DBs from the high TRPOV-R categories (high, higher, and highest) as soon as one of the sub-indexes is below 5, the relatively high levels of accessibility on the island, compared to rural areas, might obscure some reality on the ground. This is further discussed in the next section, when looking separately at the inaccessibility and marginalization sub-indexes.

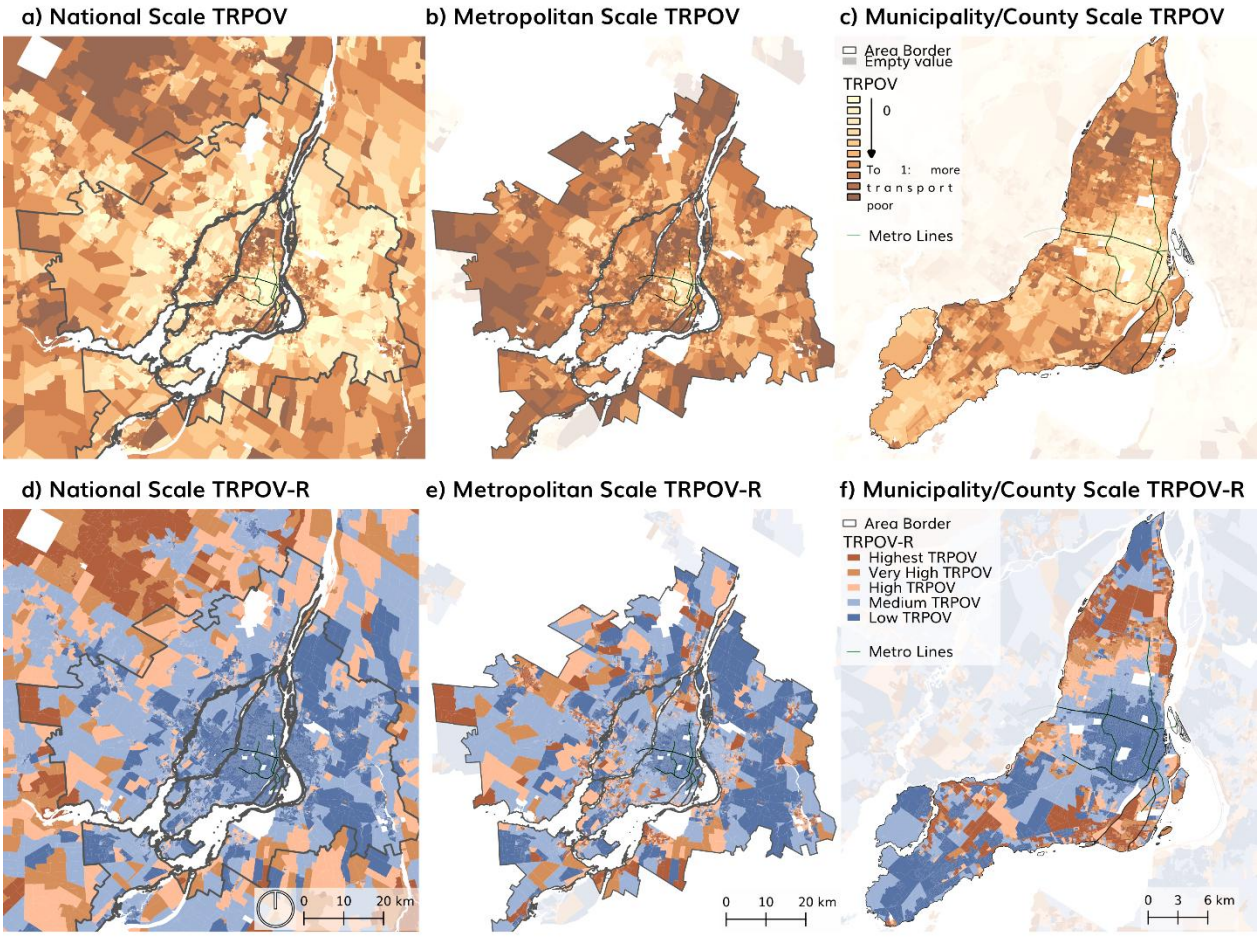

Figure A.3 Geographic patterns of TRPOV and TRPOV-R at different scales in the Montréal Census Metropolitan Area.

Looking now at the numerical results, **Figure A.4** displays the proportion of the population of the Montréal Island in areas in each category of TRPOV-R, calculated for the three different geographic scales. At the *national* level, the ranking compares all DBs in the country, from the densest urban area to the most remote rural area. In this light, any DB close to the Montréal metropolitan region, or other urban areas, has better accessibility than the most remote areas in the

country. As the scale decreases, the index only compares DBs within each limit (Montréal metropolitan region and Montréal Island), meaning that the index will display the phenomenon in a local perspective.

Here, from a total of 2,004,265 inhabitants in the Montréal Metropolitan region, the percentage of the population in areas with high levels of TRPOV-R (high, very high, and highest) varies from 0.03% at the *national scale*, to 8.5% at the *metropolitan scale*, and to 37% at the *municipal scale*. Most notably, at the *national scale*, none of the population is in the two highest levels of TRPOV-R. The observed trend reflects the fact that, at the *national scale*, when comparing to all DBs in Canada, almost all DBs on the Montréal Island are in a better position in terms of transport poverty (largely due to lower inaccessibility). This is to be expected given that the Montréal Island is characterized by a more mixed and dense land use and an extensive public transport network.

On the contrary, the percentage of the population in the Middle and Low categories decreases as the geographical scale becomes more local. This means that, when compared with the metropolitan or municipal context to which they belong, more DBs do fall in the three highest categories of TRPOV-R. Whereas most of the Island displays important advantages in terms of accessibility when compared to the rest of the country, the local scales enables considering areas that are characterized by low levels of accessibility in a an urban context.

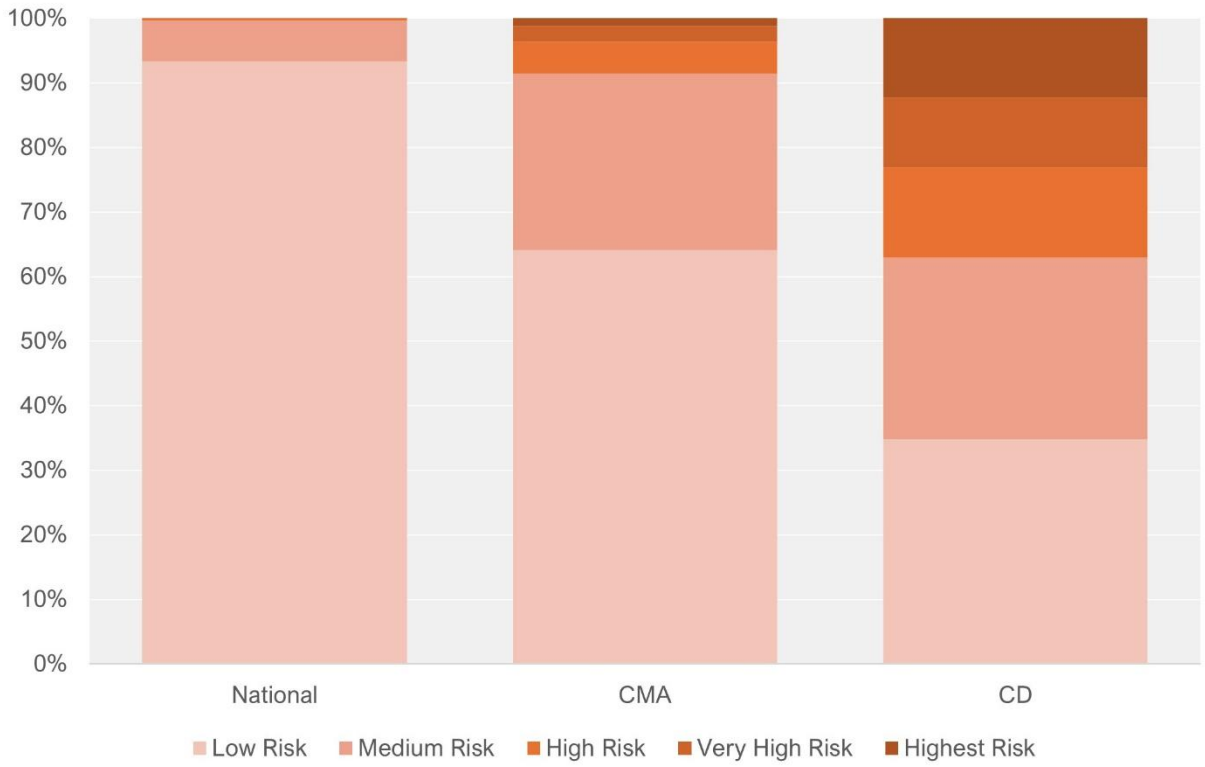

Figure A.4 Percentage of population in DBs in the different categories of TRPOV-R in the Montréal Island, calculated for three different geographic scales.

Considering the variations observed in **Figure A.4**, it is interesting to assess how scale affects the results for the whole country. **Table A.2** presents both the raw number and the proportion of the population falling in each level of TRPOV-R, based on the geographic scales at which the calculations are conducted, for the whole country. For the *metropolitan scale*, the raw numbers are smaller, since only the population in urban areas is considered. It is also important to remember that the *municipality/county* scale includes the rural population, but from a local perspective.

When analyzing the whole country, putting the three categories of high TRPOV-R together (high, very high, highest), at the *national scale*, there is 16% of the population, roughly 6.1 million people, in these categories; there is 27% of the population with the *metropolitan* scaling, meaning around 8.4 million people; and 27% of the population at with the *municipality/county* scaling, which implies around 10.2 million people (**Table A.2**). These variations highlight the limits of interpreting the results for a whole country or region, since they are highly dependent on the context and on the scaling approach, which in fact it does not change the lived experience of individuals in these areas.

It is worth noting that the rescaling process allows for a local assessment of TRPOV-R, which transforms these measures to an operative scale for local authorities. Thereby, it might not be relevant to aggregate these results at the national level, depending on the purpose of the analysis. Their relative nature is also highlighted and explored in the next section, as the index can be used to compare the situation between different regions/areas.

Table A.2: Populations per TRPOV-R type in Canada.

	National		*Metropolitan*		*Municipality/County*	
TRPOV-R Type	Population	% from total	Population	% from total	Population	% from total
Highest TRPOV	1,207,409	3%	1,964,240	6%	3,015,660	8%
Very High TRPOV	1,906,820	5%	2,670,190	9%	3,047,013	8%
High TRPOV	3,021,977	8%	3,762,487	12%	4,183,869	11%
Medium TRPOV	12,099,290	33%	10,690,437	35%	11,610,010	32%
Low TRPOV	18,215,927	50%	11,788,701	38%	14,594,871	40%
Total	36,451,423	100%	30,876,055	100%	36,451,423	100%

How do marginalization and inaccessibility interact and shape transport poverty in urban areas in Canada?

To understand the interactions between marginalization, inaccessibility, and transport poverty, **Figure A.5** shows the disaggregated results for Montréal Metropolitan region as an example. The quintiles values are used in this figure. The image shows that marginalization is a mainly urban, central phenomenon, while inaccessibility is mostly suburban/rural. When combining the two sub-indexes, the highest values of TRPOV can be seen in the areas that surround the urban core, as marginalized areas are located not immediately next to public transport stations, but still relatively close to services. Other areas with high values of TRPOV are found in the most peripheral areas, where the highest values of inaccessibility can be found.

When looking at the TRPOV-R results for the Montréal metropolitan region (**Figure A.3e**), transport poor areas are mostly located in the western and eastern tips of the Montréal Island, and in the periphery. Notably, the TRPOV index shows a higher concentration of DBs in the high transport poverty deciles on the Island (**Figure A.3b**) as compared to the TRPOV-R. This can be explained by the marginalization and inaccessibility subindexes presented here. **Figure A.5** shows that Montréal Island is characterized by a majority of DBs in the high marginalization quintiles, but a low proportion in the highest inaccessibility deciles, when calculated at the metropolitan

region level. Given the classification rule that place DBs in the lower TRPOV-R categories when either marginalization or inaccessibility is low, the high proportion of DB falling in the lower inaccessibility deciles on the Island leads to a low proportion of DBs with a high TRPOV-R. When looking at the municipal scale (**Figure A.3f**), there are several DBs in the high TRPOV-R categories, because many fall in high inaccessibility deciles when compared with the municipality and not the metropolitan region, again highlighting the impact of scale, but also the choice of measure.

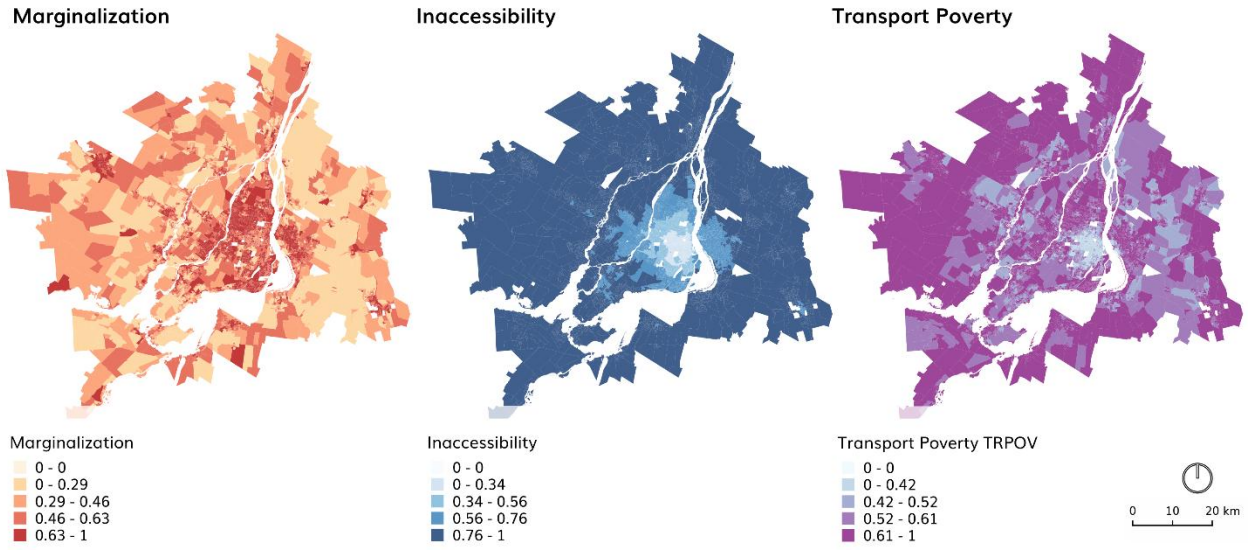

Figure A.5 Interactions between Marginalization, Inaccessibility, and TRPOV.

We now turn to the urban areas results for the whole country, considering only the CMAs and CAs, and with calculations done at the *metropolitan* scale. This analysis sheds light on the interaction between marginalization, inaccessibility and transport poverty at the national level, and sets the basis for comparative analyses. We first investigate the four indexes (marginalization, inaccessibility, TRPOV, and TROV-R) as a function of the population size of the metropolitan regions, knowing that the land use and transport systems are closely influenced by the population size in the Canadian context. It is important to note that the y-axis ranges were defined based on the range of each index, no values were excluded below the minimal limit.

An analysis of the mean values of marginalization for the 152 urban areas in Canada shows that marginalization varies from 0.29 to 0.67. As can be observed in **Figure A.6**, the most populated cities have values around 0.5, while the intermediate cities vary mostly from 0.4-0.5. Then, the group of smaller cities is heterogeneously distributed, indicating a variety of conditions of

marginalization (**Figure A.6**). The size of the dots represents the number of individuals in areas with high levels of TRPOV-R.

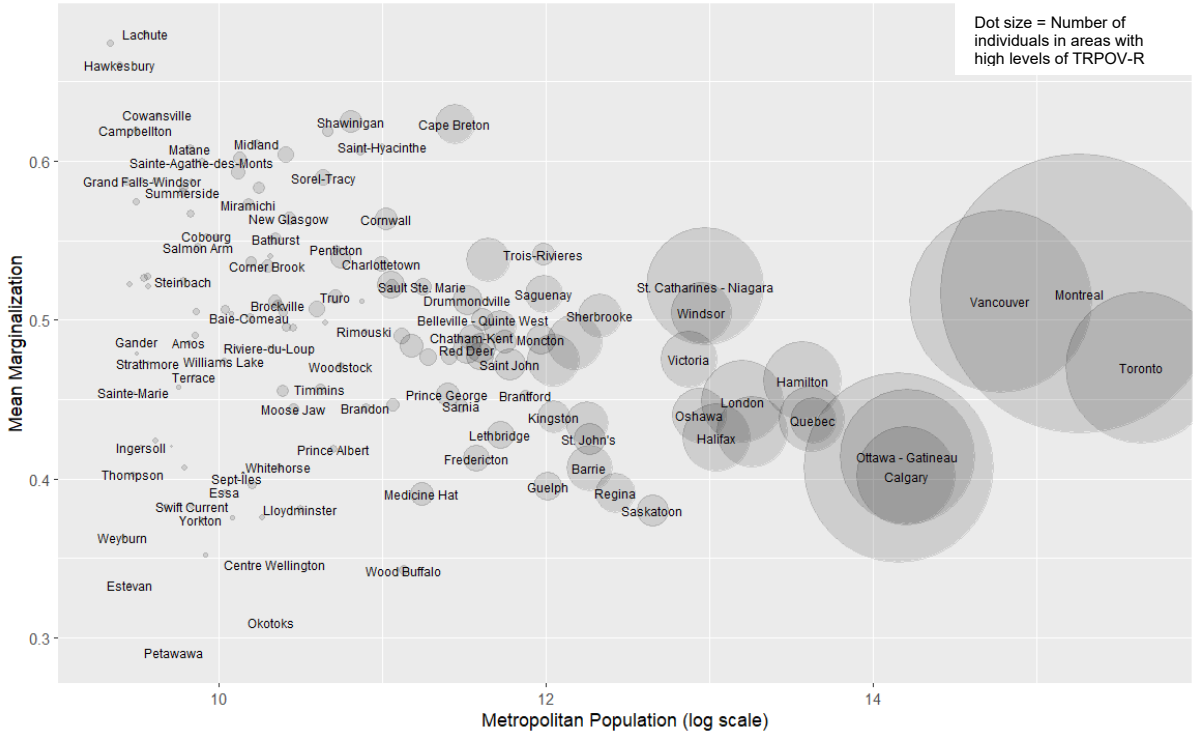

Figure A.6 Relationship between Marginalization and metropolitan area population size.

Figure A.7 shows the state of mean inaccessibility across metropolitan areas, with a variation from 0.75-1. The three largest cities are the least inaccessible. These cities are characterized by large rapid transit systems (metro, light rails, SRB and subway) and a higher population and activity density and a higher land use mix. Then, there is a clear cluster of intermediate-size cities (Edmonton, Calgary, Winnipeg, Victoria, Regina, etc.), grouped between 0.83-0.93, slightly more inaccessible than the bigger ones. Finally, there is a large group of small cities with higher values of inaccessibility from 0.9-1, although there are also some small cities at the same level of the intermediate ones. The general trend is for larger cities to be more accessible, but a detailed look calls for a deeper reflection on why small towns have such low levels of inaccessibility (bottom left, e.g., Stratford, Victoriaville), similar to larger cities such as Calgary, Victoria, or Quebec, despite their size.

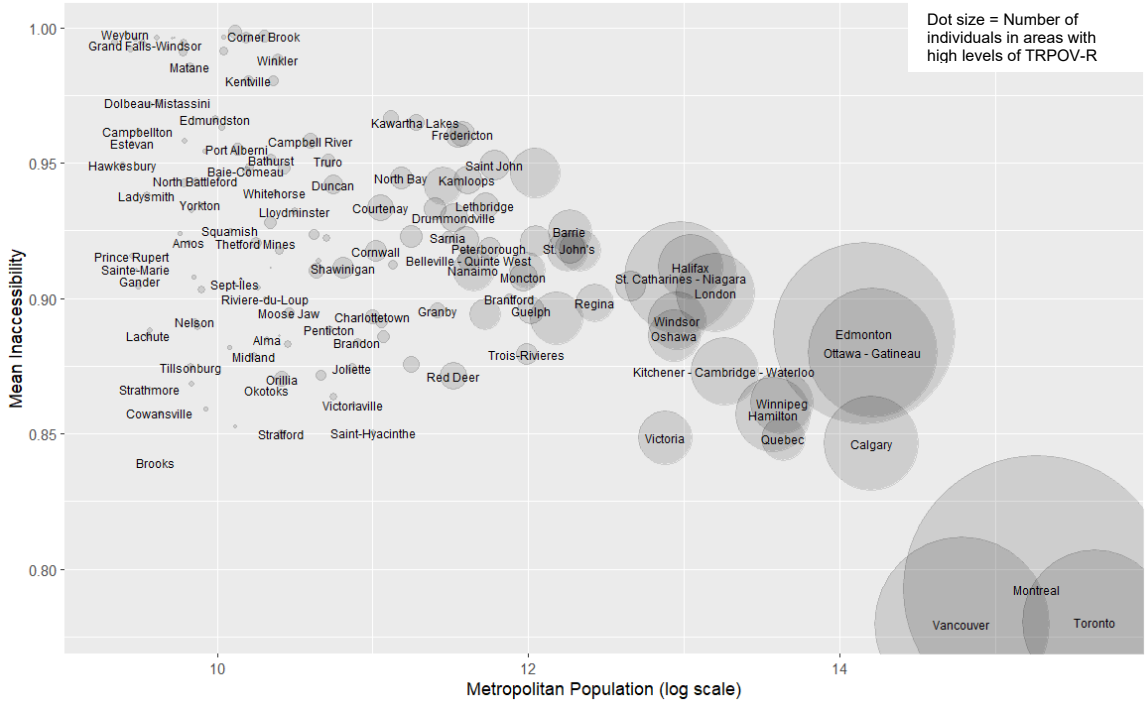

Figure A.7 Relationship between inaccessibility and metropolitan area population size.

Looking now at transport poverty (TRPOV), **Figure A.8** shows a variation from 0.65-0.83. The biggest cities, and most intermediate cities, are at the lowest end of transport poverty, until around 0.67. Then, the cloud of smaller cities is spread roughly from 0.67-1, with some exceptions. This indicates that, based on the current methodology, smaller municipalities or administrative units face starker situations of transport poverty. This trend seems more linear than for the two sub-indexes.

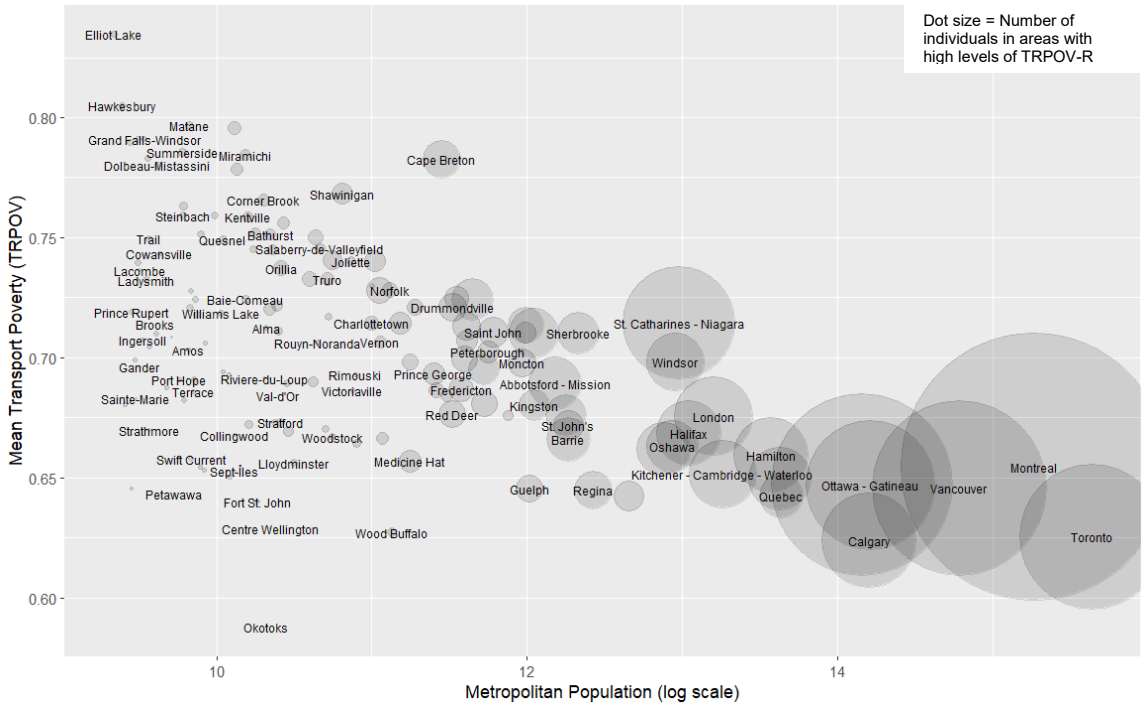

Figure A.8 Relationship between transport poverty and CMA/CA population size.

As for a TRPOV-R, the categories Highest, Very High, and High were aggregated for a general assessment across metropolitan areas. **Figure A.9** shows the proportion of individuals in DBs with high TRPOV-R as a function of the size of the metropolitan region. Results show that larger urban areas typically have lower proportions of individuals in areas with high TRPOV-R (with a number of small urban agglomerations – top left – with a proportion above to 75%). However, when considering the absolute number, the amount of population in DBs with high TRPOV-R in larger areas is higher than those in small cities with large proportions of the population in high TRPOVR-R, given the population size. We also note that the trends for TRPOV and TRPOV-R are relatively similar, at the national level.

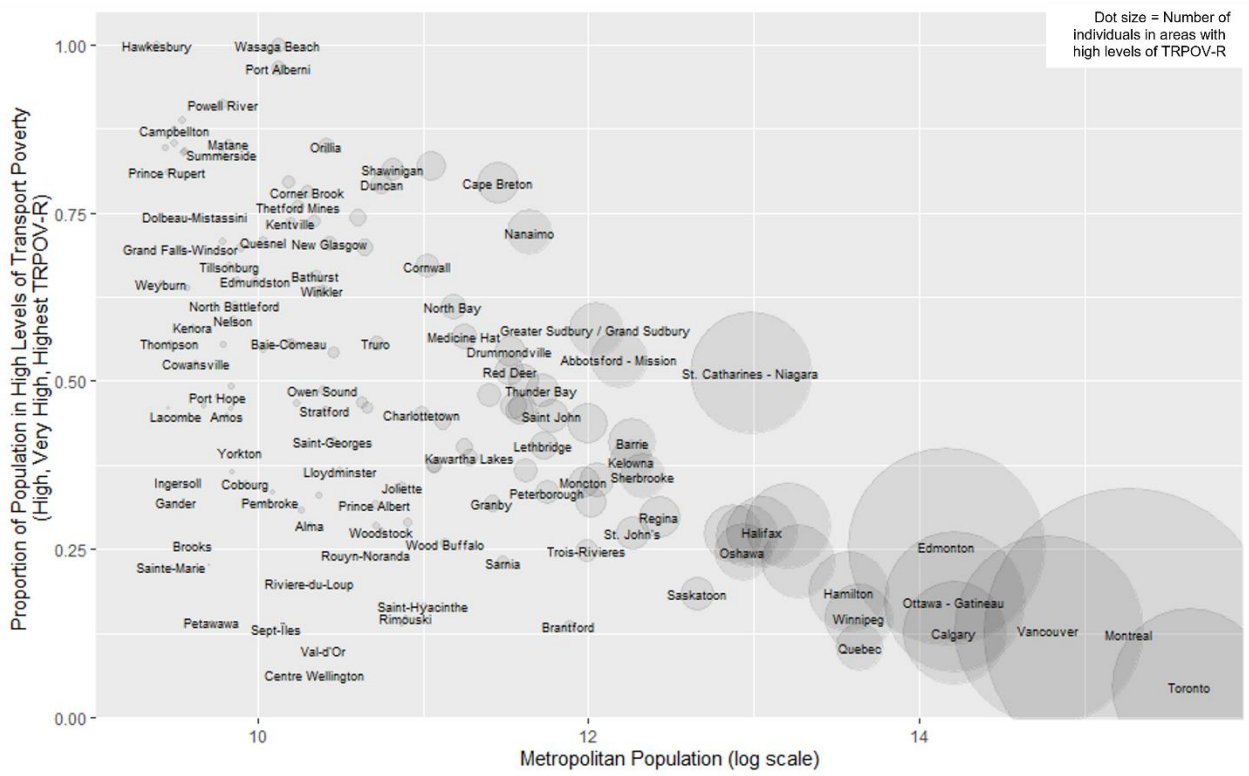

Figure A.9 Relationship between the proportion of the population at high levels of TRPOV-R and metropolitan area population size.

To further explore the relationship between marginalization and inaccessibility, a refined analysis of the distribution of marginalization in relation to inaccessibility in the ten largest urban areas is presented in **Figure A.10**. The distribution of the inaccessibility sub-index is presented using a boxplot for each marginalization quintile (quintile 5 means more marginalized). It is worth noting these do not correspond to the 5 TRPOV-R classes, but a quintile classification of marginalization alone for illustrative purposes. The results show that in all 10 urban areas (Toronto, Montreal, Vancouver, Ottawa, Calgary, Edmonton, Winnipeg, Quebec, Hamilton and the conurbation of Kitchener-Cambridge-Waterloo), the population in the fifth quintile has a higher accessibility than in the first, a condition that shows more equity in the distribution of transport services in these cities. This is in line with the results observed in **Figure A.8** and **A.9**: the largest metropolitan areas also tend to be less transport poor (TRPOV and TRPOV-R).

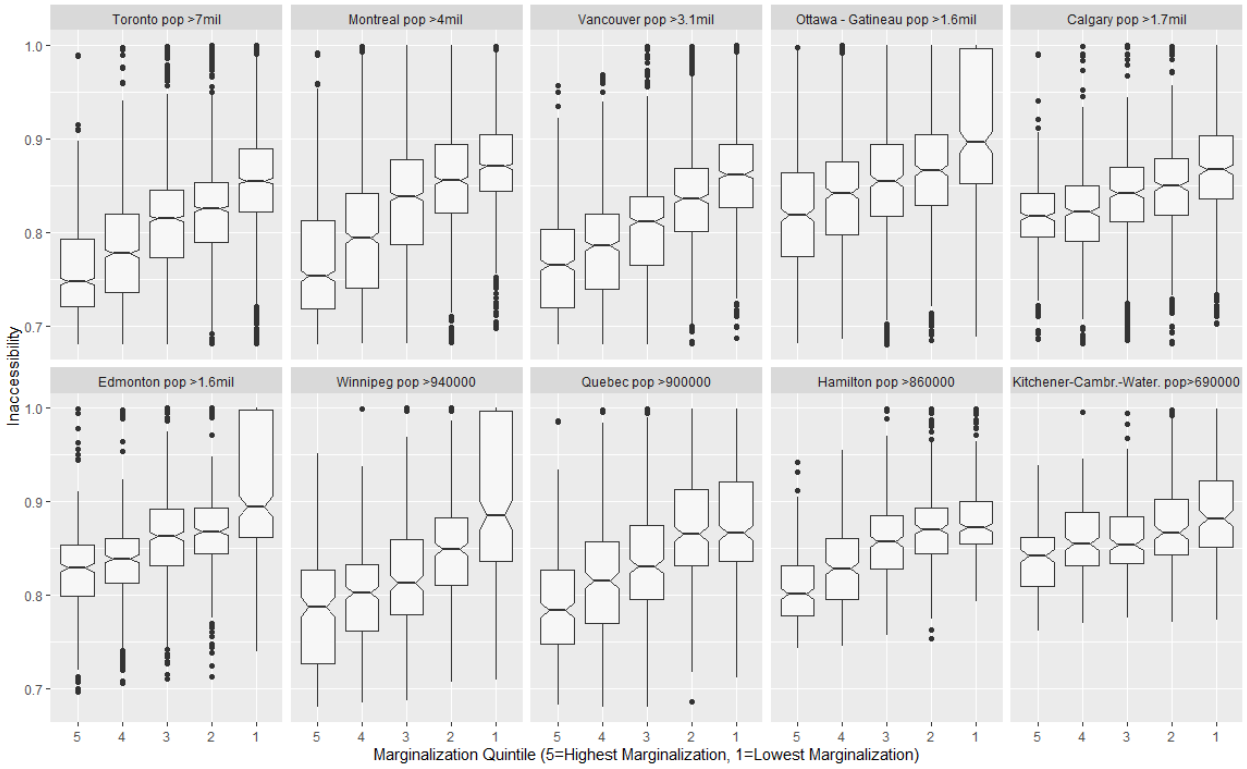

Figure A.10 Distribution of marginalization in relation to inaccessibility.

To further assess these relations, a spearman rank correlation was applied using all values, results shown in **Figure A.11**. With all p-values lower than 0.01, the results suggest a statistically significant correlation between the marginalization and inaccessibility index in all 10 cities: DBs with low inaccessibility levels typically have low marginalization levels. Nonetheless, some variation is observed in the strength of the correlation, with coefficients varying from 0.35 to 0.54. Notably, whereas Toronto and Quebec have the lowest proportion of individuals in transport poor areas (**Figure A.9**), they do not necessarily have the most equitable distribution of accessibility and marginalization when looking at the full distribution. This points towards further analysis to validate and assess the relationship between these results and the lived experiences of transport poverty.

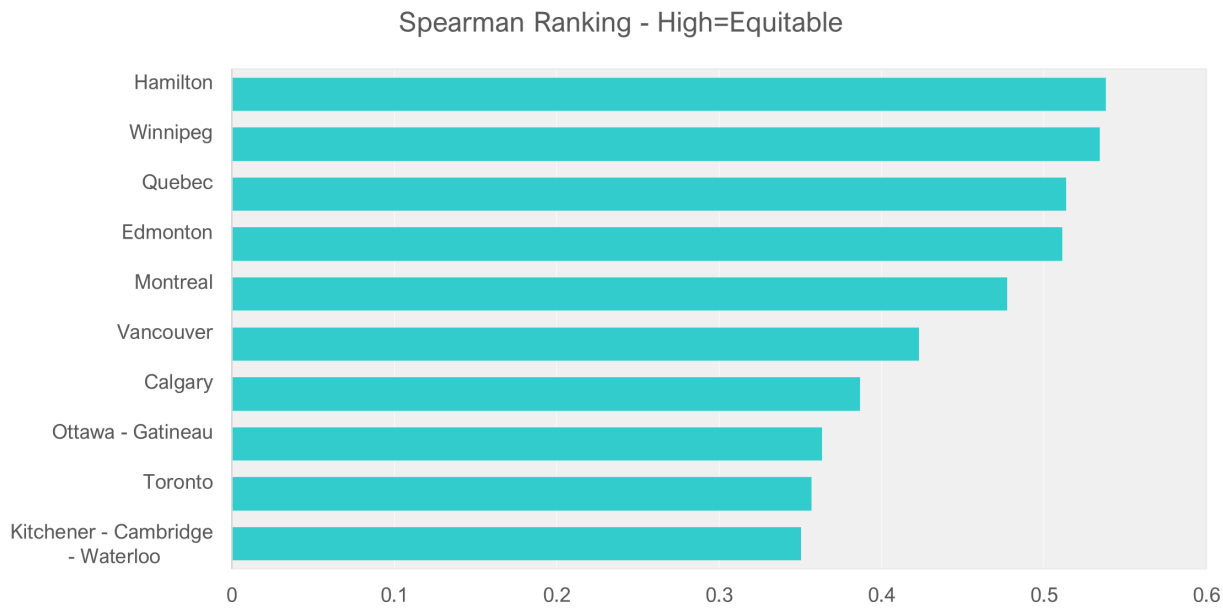

Figure A.11 Spearman vertical equity ranking of accessibility and marginalization, per CMA.

Discussion

This study proposes a methodology to measure transport poverty at the nation-wide scale, with Canada as a case study. The first objective was the design of the methodology itself, with a focus on the capacity to compare the situation between areas in the country and also to be used within local boundaries for planning purposes. The second objective was to assesses the opportunities and challenges faced in this process, of creating an easily interpretable methodology. The third objective was to demonstrate potential uses of the methodology. The process of generating this methodology and assessing its potential produced several challenges, among them the availability and quality of the data, the interpretation of a nation-wide measure in a heterogenous territory, and the use of the methodology and potential policy implications.

Data

One of the challenges of measuring transport poverty nationally is the availability of nation-wide data with the same geographic detail for all units of analysis, knowing that the standards and resources available for data collection can vary greatly between provinces and municipalities. To face the dissimilar data challenge, this research used census data and nationally available measures of accessibility to different types of destinations. This decision guarantees a homogenous standard of dataset for all geographies analyzed. Further, a previous analysis of transport poverty (Berry et

al., 2016) mentions the exclusive use of job access data as a limitation, since it does not assess possible destinations for retired or unemployed individuals, and other travel purposes. Our study overcomes this limitation by including accessibility to different types of destinations, including leisure, culture and groceries, which could capture movement of potentially vulnerable groups, like the elderly and those in charge of care-taking tasks. Moreover, this decision aligns with Lucas et al (2016), who recommend a combination of geographical contexts, socio-demographic characteristics, land uses and transport supply for measuring transport poverty.

Heterogenous territory

Another challenge for the creation of this methodology was the application of a concept that is shaped differently between different geographies (urban vs. rural, small agglomerations vs. metropolitan areas, etc.). This challenge was faced by creating different scales of measures that can be applied according to the administrative level that will use the methodology, transforming the measure from the national scale to the metropolitan and to the local, informing planning and analysis according to need.

Additionally, the design of a continuous index and a ranking scale allow for different uses. While the continuous index's (TRPOV) values may be high/low in absolute terms, the ranking and classification (TRPOV-R) is informative about the relative state of a unit of analysis and establishes a threshold for transport poverty. For local authorities, the indexes that more closely reflect the context of their jurisdiction may be more informative for designing interventions, when all DBs within the local administrative boundary are only compared with one another. For example, authorities interested in land use and transport planning for the metropolitan region could use the *metropolitan scale*, whereas each municipality could use the *municipal scale* to prioritize local interventions. The usefulness of this scalability is particularly interesting as transport receives major focus from local and national authorities as a key component to achieve equity and better quality of life in cities.

Methodology use and potential policy implications

With an array of examples of how the methodology can be used to inform decision-making in planning processes, we presented two distinct analyses to demonstrate the diversity of the information included in the indexes, their usefulness, and the possibilities of these measures for transport practitioners and examples of policy approaches. These analyses do not aim to report on

the state of transport poverty in Canada, but to showcase different possibilities of the use of the methodology for planning purposes and for providing policy recommendations. Our results show that the smallest metropolitan areas have larger proportions of the population at higher levels of transport poverty, and higher transport poverty indexes, implying a gap or imbalance of the conditions between different metropolitan areas. This is expected in the context of Canada, knowing that smaller metropolitan areas may concentrate high levels of marginalization, and are typically located in low-density areas, where land use and transport systems are closely tied to a higher car dependency.

Another result is that, overall, larger cities tend to be more accessible, with a few exceptions with levels of access similar to larger cities despite their size. Additionally, results showed that intermediate cities show more vertical equity in accessibility than larger areas like Toronto or Vancouver, consistent with the results of Allen and Farber (2019). Transport and land use systems in these towns may be investigated as examples of good practices. Similarly, the large variations in inaccessibility among smaller towns is worth further investigation.

Policy makers could use the findings of this methodology to design a system of prioritization of investments in transport and infrastructure for metropolitan areas. In this example, the methodology can be used to advocate for giving smaller metropolitan areas with a high proportion in highest levels of TRPOV first priority. This would contribute to territorial equity, while also promoting sustainable land use and transport systems nationally. Then, a second stage of investment could be addressed to larger cities, thereby catering to a higher number of people. While the proportion of people at high TRPOV is lower, they are highly dense areas and the actual amount of population in areas of high TRPOV is high. Such a measure could reduce the gap of the population between big and small cities while also improving the conditions of existing transport systems to balance benefits. This index shows the importance of keeping a balance between proportion of the population and absolute numbers when planning the distribution of benefits of new transport investments. It is important to remember that by the nature of this index, improvements can focus not only on public transport infrastructure and operations, but also on pedestrian and bike infrastructure quality, land use distribution, and socio-economic conditions.

The operationalization of this methodology fulfills the stated research objectives. However, it is important to remember that transport poverty is still a concept in development, and a

multidimensional one. One of the limitations of this study is the weighting system, which was based on the conventional equal weights for the final TRPOV index and the paper by Zheng et al. (2019) for the inaccessibility component. Additionally, given that the marginalization index varies more than the inaccessibility index, there is an effect on the results, implying that different weights could balance this difference in range. The methodology allows for the adjustment of weights to address this limitation.

Further, the 50% weighting of the marginalization and inaccessibility components implies an equal contribution of both measures, but can explored further, as marginalization showed higher values in larger cities, whereas inaccessibility had lower values in larger cities, and vice versa. These inverse results make clear that transport poverty is a multidimensional concept, but that the relations between components are complex, and that these must be considered in relation to the local context when operationalized in planning and policy making.

Conclusion

The design of a method to measure transport poverty at the national level in a country like Canada imposed many conceptual and practical challenges that were faced by designing a flexible methodology applicable at different scales of analysis; by using census data at the smallest geographical scale with accessibility measures calculated for the whole country; and by exploring different ways of interpreting the results.

Future research can focus on understanding what supports greater vertical equity (a concern for distributing more resources for the most disadvantaged groups (Camporeale et al., 2019)) in metropolitan areas. Further efforts could also investigate the relationship between vertical equity and the TRPOV-R and TRPOV results. From a vertical equity standpoint, future studies could build on the current study to assess how other socio-economic characteristics, such as gender and disability, could be accounted for in a broader framework, as we acknowledge that our index only partially capture vulnerability. Further sensitivity analyses with different weights are also warranted to understand potential variability in the results, especially testing differences in the weight of transport modes. The influence of including accessibility by car in the Inaccessibility component could also be analyzed. Whereas this study focused on public transport, cycling, and walking as they are typically more accessible to vulnerable populations (given their lower costs), it is important to acknowledge that car dependency (and forced car ownership) is an important

reality in lower density areas. Future studies could test the impact of assigning different weights to accessibility by car and analyze how it relates to the different contextual realities.

Another important avenue for future research is to examine how these results related to the lived experiences of individuals. Therefore, future research should validate both TRPOV and TRPOV-R on the grounds of understanding the representativeness of the index and its relationship with lived experiences. As such, validation of the mathematical structure of the index could be explored, as well as external validation of the lived experiences of transport poverty. In line with this, understanding the relationships between these lived experiences and mode captivity would be advised. While the proposed index does not capture mode captivity as such, it does reflect on the lack of access to destinations via active and public transport, which is a basis for modal captivity (Molloy et al., 2024). Similarly, more efforts are warranted to assess how different accessibility calculations could impact the results. Notably, accessibility measures accounting for public transport quality (L. Liu et al., 2024), travel cost (El-Geneidy et al., 2016), road characteristics, and safety should be considered, as developed in recent research (Tavakoli et al., 2024). Other types of accessibility measures, destinations, weights, and parameters (e.g., peak public transport travel times, distance decay function) could also be tested.

Local authorities can use the methodology for planning targeted interventions in their administrative boundaries, while it can provide national and regional authorities insights to compare the different areas. In the case of Canada, these results allow for identifying areas of interest for both the public transport and active mobility funds, for example. But more profoundly, it shows that the inaccessibility index (varies only from 75-100 nationally) is the largest contributor to transport poverty, resulting in a relatively general condition of lack of access to opportunities. This could allow for designing a national strategy of supporting transport systems towards improving equity.

APPENDIX B:TABLE OF VARIABLES USED PER DATASET

Table B.1: Table of variables used per dataset.

Article	Dataset Name	Source	Year	Variable	Description	Use	Type
Article 1	Canadian Marginalization Index (CAN-Marg)	Matheson et al. 2012	2016	DA16UID	Dissemination area identification code	Joining geography and data	Continuous
				Households and Dwellings Q.	Quintile of the Households and Dwellings component	Component for the marginalization index	Continuous
				Material Resources Q.	Quintile of the Material Resources component	Component for the marginalization index	Continuous
				Age and Labour force Q.	Quintile of the Age and Labour force component	Component for the marginalization index	Continuous
				Immigration and Visible Minorities Q.	Quintile of the Immigration and Visible Minorities component	Component for the marginalization index	Continuous
	Canada's Spatial Access Measures	Statistics Canada	2022	DBUID	Dissemination block identification code	Joining geography and data	Continuous
				Accessibility to health - transit (peak), transit (off-peak), cycling, walking	Normalized accessibility measure to the destination type (per dissemination block)	Component for the inaccessibility index	Continuous
				Accessibility to primary education - transit (peak), transit (off-peak), cycling, walking	Normalized accessibility measure to the destination type (per dissemination block)	Component for the inaccessibility index	Continuous
				Accessibility to postsecondary education - transit (peak), transit (off-peak), cycling, walking	Normalized accessibility measure to the destination type (per dissemination block)	Component for the inaccessibility index	Continuous
				Accessibility to groceries - transit (peak), transit (off-peak), cycling, walking	Normalized accessibility measure to the destination type (per dissemination block)	Component for the inaccessibility index	Continuous

Table B.2: Table of variables used per dataset. (continued)

Article	Dataset Name	Source	Year	Variable	Description	Use	Type
				Accessibility to recreation - transit (peak), transit (off-peak), cycling, walking	Normalized accessibility measure to the destination type (per dissemination block)	Component for the inaccessibility index	Continuous
				Accessibility to culture - transit (peak), transit (off-peak), cycling, walking	Normalized accessibility measure to the destination type (per dissemination block)	Component for the inaccessibility index	Continuous
				Accessibility to employment - transit (peak), transit (off-peak), cycling, walking	Normalized accessibility measure to the destination type (per dissemination block)	Component for the inaccessibility index	Continuous
	Census Profile, 2016 Census of Population	Statistics Canada	2016	UID	Dissemination area identification code	Joining geography and data	Continuous
				Number Females	Number Females	Population weight (women)	Continuous
				Number Males	Number Males	Population weight (men)	Continuous
Article 2	Origin-Destination Survey of Montréal	Regional Authority of Metropolitan Transport (ARTM)	2018	ipere	Trip identification code	Joining geography and data	Continuous
				Sex	Women/men	Gender data classifier	Categorical
				Age	Age of the person	To select people over 18 to perform the analysis To count children in the household Component in regression analysis	Continuous
				Mobilized	Mobility of the person	To select those who moved locations to perform the analysis	Categorical
				Purpose	Trip purpose	Component in regression analysis	Categorical
				Income	Income category of the household	Component in regression analysis	Categorical

Table B.3: Table of variables used per dataset. (continued)

Article	Dataset Name	Source	Year	Variable	Description	Use	Type
				Car number	Number of vehicles of the households	Component in regression analysis	Continuous
				Longitude-origin	Longitude coordinate origin	Geolocate origins and destinations Component to calculate distance of the trip	Continuous
				Latitude-origin	Latitude coordinate origin	Geolocate origins and destinations Component to calculate distance of the trip	Continuous
				Longitude-destination	Longitude coordinate destination	Geolocate origins and destinations Component to calculate distance of the trip	Continuous
				Latitude-destination	Latitude coordinate destination	Geolocate origins and destinations Component to calculate distance of the trip	Continuous
Article 3	Origin-Destination Survey of Montréal	Regional Authority of Metropolitan Transport (ARTM)	2018	ipere	Trip identification code	Joining geography and data	Continuous
				Sex	Women/men	Gender data classifier	Categorical
				Age	Age of the person	To select people over 18 to perform the analysis	Categorical
				Mobilized	Mobility if the person	To select those who moved to perform the analysis	Categorical
				Purpose	Trip purpose	Component in regression analysis	Categorical
				Mode	Trip mode	Component in regression analysis	Categorical
				Income	Income category of the household	Component in regression analysis	Categorical

Table B.4: Table of variables used per dataset. (continued)

Article	Dataset Name	Source	Year	Variable	Description	Use	Type
				Longitude-origin	Longitude coordinate origin	Geolocate origins and destinations Generate flows Component to calculate distance of the trip	Continuous
				Latitude-origin	Latitude coordinate origin	Geolocate origins and destinations Generate flows Component to calculate distance of the trip	Continuous
				Longitude-destination	Longitude coordinate destination	Geolocate origins and destinations Generate flows Component to calculate distance of the trip	Continuous
				Latitude-destination	Latitude coordinate destination	Geolocate origins and destinations Generate flows Component to calculate distance of the trip	Continuous
Article 4	Montréal Mobility Segmentation Survey	Regional Authority of Metropolitan Transport (ARTM)	2023	Gender	Gender of the person	Gender data classifier	Categorical
				Main mode	Main mode used for transportation	Generate dissonance type	Categorical
				Preferred mode	Preferred mode if they can choose	Generate dissonance type	Categorical
				24 criteria to choose a mode	Rating on a scale 1-10 of the importance given to 24 different criteria to choose mode	Component in descriptive analyses Component in factor analysisComponent in regression	Continuous
				Opinions about metro	Adjectives used to describe a transport mode (metro)	Component in descriptive analyses Component in factor analysis Component in regression	Categorical

Table B.5: Table of variables used per dataset. (continued)

Article	Dataset Name	Source	Year	Variable	Description	Use	Type
				Opinions about bus	Adjectives used to describe a transport mode (bus)	Component in descriptive analyses Component in factor analysis Component in regression	Categorical
				Opinions about cycling	Adjectives used to describe a transport mode (cycling)	Component in descriptive analyses Component in factor analysis Component in regression	Categorical
				Opinions about walking	Adjectives used to describe a transport mode (walking)	Component in descriptive analyses Component in factor analysis Component in regression	Categorical
				Public transport card ownership	If the person owns a public transport pass	Component in regression	Categorical
				Subscription to carshare	If the person has a subscription to a carshare system	Component in regression	Categorical
				Residence ownership	If the person owns their house	Component in regression	Categorical
				Education level	Highest education level of the person (primary, secondary, university or higher)	Component in regression	Categorical
				Occupation	Main occupation of the person	Component in regression	Categorical

APPENDIX C: APPENDIX TABLE FOR CHAPTER 7, SECTION 7.4.2.

Table C.1. Chi-squared test of adjectives used to describe modes, by gender. Significant values in red text.

	Metro					Bus			
Adjective	*statistic*	*p-value*	*n women*	*n men*	*Adjective*	*statistic*	*p-value*	*n women*	*n men*
Affordable	2.115	0.146	166	138	Doesn't support my lifestyle	0.118	0.731	217	205
Doesn't support my lifestyle	5.850	**0.016**	193	147	Busy	27.148	**0.000**	331	217
Busy	23.593	**0.000**	376	263	Dirty	9.782	**0.002**	178	123
Dirty	31.340	**0.000**	237	133	Painful	9.370	**0.002**	165	113
Ecofriendly	0.070	0.792	232	221	Restrictive	0.842	0.359	191	170
Efficient	1.992	0.158	214	183	Slow	0.007	0.931	212	210
Fast	5.411	**0.020**	236	187	Uncomfortable	0.180	0.671	177	165
Hard to access	0.327	0.567	225	232	Unreliable	1.597	0.206	153	129
Simple	2.147	0.143	164	136	Affordable	1.768	0.184	153	128
Stressful	28.249	**0.000**	198	107	Easy to access	5.815	**0.016**	194	148
	Cycling					**Walking**			
Adjective	*statistic*	*p-value*	*n women*	*n men*	*Adjective*	*statistic*	*p-value*	*n women*	*n men*
Affordable	0.547	0.459	234	214	Affordable	9.999	**0.002**	264	197
Doesn't support my lifestyle	25.010	**0.000**	279	277	Easy to access	2.192	0.139	173	144
Clean	2.291	0.130	116	137	Ecofriendly	15.179	**0.000**	384	290
Dangerous	2.444	0.118	193	161	Pleasant	1.691	0.193	261	229
Ecofriendly	0.316	0.574	356	335	Supports my lifestyle	1.063	0.303	161	140
Pleasant	1.929	0.165	135	155	Quiet	0.065	0.799	173	164
Quiet	5.122	**0.024**	167	204	Relaxing	4.704	**0.030**	306	254
Simple	2.747	0.097	166	192	Reliable	1.857	0.173	159	133
Slow	0.264	0.607	199	205	Simple	0.795	0.373	280	255
Uncomfortable	5.265	**0.022**	193	149	Slow	11.427	**0.001**	299	224