Land-use and Transportation Interactions through the Lenses of Two-Worker Households, Rising Commuting Costs and Transit-Oriented Development

By

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy

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Integrated land-use and transportation planning is critical for dealing with the challenges of urbanization and for ensuring the social, economic and environmental sustainability of our cities. Effective planning requires a proper understanding of land-use and transportation interactions. To improve this understanding, the research conducted in this dissertation includes empirical studies to examine interactions in the contexts of two-worker households, rising commuting costs and transit-oriented development.

First, econometric models are developed to examine the relationship between factors related to the transportation network and the land-use configuration of two-worker households. Geometrical variables are utilized as descriptors of the land-use configuration and are used to draw relationships with commuting modal accessibility and commuting trade-offs. Second, discrete choice models are developed to examine household choices concerning land-use configuration in the event of significant increases in commuting costs. A discrete choice model is
also developed to examine the direction of home location choice relative to the workplace. Framing the model in this manner enables the identification of factors that may contribute to urban sprawl. Third, empirical models are developed to examine travel behaviour in the context of transit-oriented development. Trip generation models for rail trips with walk access/egress are developed to identify the influence of station-level attributes and characteristics of the surrounding environment. The Living Near Transit survey is then designed to collect disaggregate household-level data from households who reside within a walking catchment area of GO Transit rail stations. The collected data is used to develop a behavioural model that identifies specific demographic factors and transit-oriented development characteristics that influence mode choices.

The empirical studies in this dissertation contribute to the existing body of literature by revealing new findings of land-use and transportation interactions in the three noted contexts and have corresponding policy implications.
Acknowledgments

This thesis is the culmination of my academic experience at the University of Toronto, which began nearly two decades ago as an undergraduate student in the Department of Civil Engineering. There are several people at the University of Toronto who have had a profound impact on my journey and academic development. First and foremost, I would like to express my sincere gratitude and appreciation to my supervisor, Professor Khandker M. Nurul Habib. Your guidance, dedication and friendship over the past several years has been critical to my success. I am greatly indebted to you and this thesis would not have been possible without you. Your work ethic and unwavering commitment to your students is inspiring. I consider myself very lucky to have you as my supervisor and hope we can continue working together in the future.

Secondly, I would like to thank Professor Amer Shalaby who provided valuable insight and support. It was a tremendous privilege to work with you on aspects of this research. I learned a great deal from you and very much appreciate the time you have taken to assist me. My first experience with you was in 2003 when I was enrolled in your transportation design course. It humbles me to know that I have been learning from you since then.

I would like to thank Professor Matthew Roorda who provided insightful comments on this thesis which I greatly appreciate and have carefully considered. I remember taking your transportation planning course when I had just embarked on this PhD journey. I recall marveling at your ability to teach abstract concepts and convey ideas with real world examples. I continue to refer to those course notes.

I would like to thank Professor Marianne Hatzopolou for being part of my PhD committee. I am highly appreciative of your valuable time. Your research on air pollution is inspiring and is a reminder that engineering, in essence, is for the betterment of our world.

Finally, I would like to thank Professor Luis F. Miranda-Moreno for serving as the external reviewer for my final PhD defense. Your insightful comments are very much appreciated and highlight the importance of contemplating alternative methodologies, which motivate future research in land-use and transportation interactions.
Since a very early age, my favourite pastime has been reading. In fact, during my graduate studies, I would avoid Gerstein library as I could not resist the temptation of browsing the bookshelves for biographies of exceptional scientists. In addition to the professors who I have had the pleasure of learning from firsthand, there are two textbooks that I would like to acknowledge. I would like to thank Professor Eric J. Miller and Michael Meyer for their book, *Urban Transportation Planning*, which I have read many times over. I would also like to thank Kenneth E. Train for his book, *Discrete Choice Methods with Simulation*, which has been immensely helpful.

The University of Toronto has been my second home for several years and I am grateful to the staff and students whom I have encountered along the way. Special thanks to Professor Brenda McCabe and Professor Brent Sleep for your guidance in steering me through the initial phases of the application process for my post-graduate studies. You have both made me feel welcome returning to the University of Toronto after my time away. Also, a special thanks to Professor Peter M. Wright. Although you may never read this, I want to acknowledge the support you provided in my very first undergraduate year. At the time I was 17 years old and considering switching my program due to the immense academic pressure all first years seem to face. You encouraged me to persist and try my best. If it was not for your words of encouragement, I may not have become a civil engineer and may not be completing a PhD, both of which are important parts of who I am. Finally, I must acknowledge my dear friends in the Department of Civil Engineering. Special thanks to Sami Hasnine for your friendship and especially for your ability to energize and uplift a room of tired and struggling students. Thanks to Adam Weiss for your friendship and valuable feedback on my research. Thanks to Chris Harding for your interesting conversations and points of view on transportation issues. Thanks to Elli Papaiannou for always being willing to help out even after you completed your time as a student.

Finally, I would like to thank my family and friends outside of academia for their constant love and support. I consider myself very blessed to have such loving, caring and supportive parents. Thank you for instilling the importance of higher education and teaching me from an early age that teachers and professors deserve the same respect as parents. I would like to thank my brothers, sisters-in-law, nieces and nephew for surrounding me with joy and happiness. I would like to thank my dear friends, Saba, Hamid, Ali, Khesrow, Muneeb, Jay, Daniel, Branko, Mark
and Desley for always providing comedic relief and unwavering friendship. Last but certainly not least, I would like thank my best friend and wife Stefanie for your love and constant support throughout my Masters and PhD. You are the best thing that has happened in my life. Thank you for doing my references.
Dedications

To Stefanie
List of Publications

The following chapters of this dissertation have been reproduced with modifications from previously published and presented material:

CHAPTER 4 Relationship between Modal Accessibility and the Home-Work Spatial Configuration of Two-worker Households


CHAPTER 5 Relationship between Home-Work Spatial Configuration and Commuting Trade-offs of Two-worker Households


CHAPTER 6 Mobility Tool Ownership, Home Relocation, and Home Location (relative to workplaces) Choices in the Context of Rising Commuting Costs


-Also presented at the 14th IATBR Conference, July 19-23, 2015, Windsor, UK.

CHAPTER 7 Relationship between Transit Ridership with Walk Access/Egress and Transit-Oriented Development


CHAPTER 8 MODE CHOICES OF COMMUTERS LIVING NEAR REGIONAL COMMUTER TRAIN STATIONS IN THE GTHA

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Chapter 1

1 Introduction

1.1 Chapter Overview

This chapter introduces the research conducted for this dissertation. First, a discussion of the problem statement is provided in Section 1.2. The motivation for this research is presented in Section 1.3. Finally, the dissertation overview is set out in Section 1.4.

1.2 Problem Statement

The world is in a state of continuous urbanization, with 54 percent of the world’s population residing in urban areas (United Nations, 2014). This growth in urbanization poses serious challenges in terms of social impacts, economic competitiveness, and environmental deterioration. Essential to addressing these challenges is integrated land-use and transportation planning to shape our cities in a socially, economically and environmentally sustainable manner for current and future generations. Effective planning requires a thorough understanding of the interactions between the urban land-use and transportation systems. Urban land-use is the spatial distribution of people and activities, while the transportation system facilitates the movement of people to those activities.

It is widely acknowledged that there exists a two-way interaction between land-use and transportation. This two-way interaction is manifested in several ways. The forward impact of land-use on transportation is better understood, while studies examining the reverse impact of transportation on land-use are lacking. The impact of land-use on transportation can be understood when considering that the demand for travel between activities is determined by the location of those activities as established by land-use patterns. For instance, the travel demanded for the trip to work is dictated by home and work locations. Conversely, the reverse impact of transportation on land-use can be understood when considering that transportation system improvements increase
the accessibility of certain areas, which in turn makes them more attractive for development thereby influencing the configuration of land-uses.

It is important to consider the role of transportation in the evolution of urban areas throughout history. Take for example, the era when mobility was limited to walking. The lack of mass transportation resulted in very high urban densities since only areas that were located within walking distance were considered accessible. This created a concentration of residences and economic activities in a central area. That land-use configuration changed significantly with the development of mass transportation in the streetcar era, which improved the accessibility of a larger area thus allowing the expansion of the city, the concentration of services and activities in a downtown, and the relocation of residential land-uses to the periphery. Jumping forward to the more recent era of highways, we see the decentralization of residential and employment land-uses as the automobile and transport infrastructures supported the growth of individual mobility (Muller, 1995; Rodrigue, 2013). Highway construction and the large-scale use of the private automobile initiated the process of urban sprawl, which has led to the deplorable traffic conditions and air pollution we experience today. To address these problems created in the past and to plan sustainably for the future, understanding how land-use and transportation systems interact is essential.

Therefore, the empirical research conducted in this dissertation studies the interactions between land-use and transportation in the contexts of two-worker households, rising commuting costs, and transit-oriented development. Using these three contexts provides a holistic perspective on the linkage between land-use and transportation. An improved understanding of this linkage can, in turn, facilitate the integration of land-use and transportation planning to shape our cities and deliver social, economic and environmental sustainability.

1.3 Motivation

There are two categories of research on land-use and transportation interactions. First, there are empirical studies that examine hypotheses about the expected effects of certain land-use characteristics on aspects of the transport system (i.e. modelling the effect of density on trip generation). There are also empirical studies on the reverse impact of transportation on land-use.
Second, there is research which uses integrated models that simulate human decision making and its consequences over a period of time in an urban area. The research conducted in this dissertation falls into the former category of empirical studies and consists of several empirical analyses that examine the two-way interaction in three different contexts. In the context of two-worker households, the focus is on the above noted reverse impact by considering the influence of commuting modal accessibility (transportation factor) on the spatial configuration of home and work locations (land-use factor). In the context of rising commuting costs, the research examines the joint household decision of residential mobility and changes to mobility tool ownership, which is another manifestation of the reverse impact. In the context of transit-oriented development, the research examines the impact of this type of land-use system on travel choices.

1.3.1 Motivation for Research on Two-worker Households

Two-worker households are an interesting context for studying the impact of transportation on land-use since they experience the dual constraint of considering two different work trips when making land-use decisions about home location. Furthermore, we are motivated to consider two-worker households since they are a growing portion of the population and their unique demand for travel will undoubtedly shape the land-use configuration of an urban area. Therefore, to plan appropriately for the future, their commuting behaviours and patterns should be studied.

As explained in the literature review, household-level commute mode choices and the home-work spatial configuration of two-worker households have not been jointly explored in empirical models. Therefore, the research conducted in this dissertation develops an econometric modelling framework to explore the relationship between commuting modal accessibility and the home-work spatial configuration of two-worker households. The role of spatial configuration on commuting trade-offs between members of a two-worker household is also examined. These empirical studies provide a greater understanding of how transportation system attributes influence land-uses.

1.3.2 Motivation for Research on the Impacts of Rising Commuting Costs

Understanding the influence of transportation on land-use must take into consideration accessibility, which is often interpreted as the average number and closeness of activity
opportunities that residents of a certain area possess (Wachs and Kimagai, 1973). However, the accessibility of a certain location can also be understood in terms of the ease for people to participate in activities from specific locations to a destination using a certain mode of transport (Primerano and Michael, 2005). In this sense, accessibility can be identified through some aspect of the transportation network, such as travel cost (Iacono et al., 2008). Therefore, the motivation for this research is to consider travel cost as an aspect of the transportation network and its influence on household choices of home relocation, mobility tool ownership, and home location relative to workplaces. Travel cost has been considered in previous research, however, studies considering a broad range of costs are lacking. Therefore, this research considers scenarios of significant increases to travel costs to fully capture its influence on household choices, which ultimately affect land-use configuration. Furthermore, this research explores whether significant travel cost increases will induce households to locate closer to their workplaces to mitigate travel costs, thereby reversing urban sprawl.

1.3.3 Motivation for Research on Transit-Oriented Development

Transit-oriented development (TOD) is an integrated approach to land-use and transportation planning and is a response to the rise in social, economic and environmental hardships brought on by decades of urban sprawl. TOD is a compact, mixed-use, pedestrian and cyclist friendly form of urban development that is oriented towards transit use. An important objective of TOD is to reduce reliance on the automobile and facilitate the use of public transit and active transportation modes. TOD has been the subject of several studies, however, there is a lack of empirical analyses which provide an adequate understanding of how this land-use configuration affects commuting behaviour. Therefore, the motivation of this research is to conduct empirical analyses which identify characteristics of TOD that influence mode choice behaviour. A secondary motivation for this research comes from the regional transit authority of the Greater Toronto and Hamilton Area whose objective is the development of TOD in and around their current and future rail stations.

1.4 Dissertation Overview

The overall objective of this research is to improve the understanding of land-use and transportation interactions through the contexts of two-worker households, rising commuting
costs and TOD. Also, the modelling results of this research are used to inform policies concerning land-use and transportation planning. Under each of the above-noted contexts, there are various empirical studies aimed at filling the gaps in existing literature. To meet the research objectives, various tasks are conducted and organized into the subsequent chapters of this dissertation. The layout of the dissertation is depicted in Figure 1.1.

CHAPTER 2 An extensive literature review is conducted and identifies the gaps in current research on two-worker households, household decisions affecting land-use configuration, and TOD. The studies reviewed are those which are relevant to land-use and transportation interactions.

CHAPTER 3 A conceptual framework is developed and consists of empirical studies under each of the three contexts.

CHAPTER 4 An econometric modelling structure is developed to explore the relationship between commuting modal accessibility and the home-work spatial configuration of two-worker households. This study uses collected data from households in the National Capital Region of Canada.

CHAPTER 5 Empirical models are developed to explore the role of commuting trade-offs in the home-work spatial configuration of two-worker households. This study uses data collected from a stated-adaptation survey of cross-regional commuting households in the Greater Toronto Area.

CHAPTER 6 Two discrete choice models are developed to examine household choices under scenarios of rising commuting costs in the Greater Toronto Area. The first model considers a combined choice of home relocation and mobility tool ownership changes. The second model examines the direction of home location choice relative to workplaces.

CHAPTER 7 Empirical models are developed to examine the factors affecting rail ridership with walk access and egress to and from rail stations. The study uses data extracted from a rail passenger survey conducted in the Greater Toronto and Hamilton Area.

CHAPTER 8 A hybrid revealed preference and stated preference survey is developed to collect disaggregate choice data from households in the Greater Toronto and Hamilton Area. The survey
mimics scenarios of TOD and requests households to make commuting mode choices. Subsequently, a discrete choice model is developed to examine mode choice behaviour in the context of TOD.

CHAPTER 9 The research is summarized and the contributions of this dissertation are set out. Directions for future research are also provided.
Figure 1.1: Dissertation Layout
Chapter 2

2 Literature Review

2.1 Chapter Overview

This chapter provides a review of the relevant studies in the existing body of literature. This chapter begins with an overview of the interaction between land-use and transportation in Section 2.2. Section 2.3 provides an overview of the studies related to the first context of this research, which is two-worker households. In Section 2.4, a review is provided of the studies related to residential mobility and mobility tool ownership, which are examined in the context of rising transportation costs. Section 2.5 provides an overview of TOD which is the final context for this research. Section 2.6 outlines the summary of the cited literature.

2.2 Introduction

The spatial distribution of human activities (land-uses) and the trips within the transport system to get to and from the location of those activities are inherently connected. Alonso (1964) provides one of the original conceptions for understanding the urban spatial structure and in particular the spatial relationship between households and their work activities. Alonso (1964) evaluates home location choices based on fixed work locations whereby households consider income, preferences and commuting costs to decide between lands prices and accessibility to their work location. Other similar studies, which only contemplate work locations as predetermined, also conclude that work locations drive residential relocation (Lowry, 1964). Over time, theories evolved to contemplate that relationship in a more complex light. For instance, Weinberg (1979) argues that individuals adjust accessibility or travel costs, by altering either the work or residential location or both.

It is now widely acknowledged that there exists a two-way interaction between land-use and transportation. The two-way interaction is manifested in several ways, but the impact of land-use on transportation is better understood, while studies examining the reverse impact are lacking. The impact of land-use on transportation can be understood when considering that travel demand
is derived from the need to participate in activities that occur in places disbursed throughout urban areas. For instance, when land-uses are configured in a manner which allows for the concentration of activities (i.e. through mixed-use development), shorter trips are demanded and a common outcome is an increased reliance on public transit. The other aspect of the two-way interaction is the impact of transportation on land-use, which is understood when considering accessibility created by transportation infrastructure (i.e. road network and public transit). Transportation system improvements increase the accessibility of certain locations which in turn makes them more attractive for various land-uses thereby influencing the direction of development.

According to Wegner and Fuerst (1999), there is a distinction in the types of research on transportation and land-use interactions. There are empirical studies on the relationship between urban form and travel patterns that typically examine hypotheses about the expected effects of certain land-use characteristics on aspects of the transport system. There are also empirical studies on the reverse impact, however, there are far fewer likely because of the much slower rate at which land-use changes are observed. The other type of research on transportation and land-use interactions uses integrated models which simulate human decision making and its consequences over a period of time in an urban area. This research falls into the former category of empirical studies on land-use and transportation interactions. It consists of several empirical studies that examine the two-way interactions in three different contexts of this research.

2.3 Two-worker Households

Understanding two-worker households is important for planning for future travel demand as some researchers estimate that the number of two-worker households has been growing and makes up a significant share of urban residents (White, 1988; Hotchkiss and White, 1993; and Clark et al., 2003; Habib, 2013). Statistics Canada reports that the number of households with two working parents has nearly doubled from one million in 1976 to 1.9 million in 2015. These households now also make up a significantly larger proportion of the population. Over that same 40-year period, the percentage of households with two working parents has risen from 36 percent to 69 percent (Statistics Canada, 2016). This portion of the urban population is unique in that they face dual constraints with home and commuting choices due to the two workplace locations,
which results in home-commuting trade-offs (Kim, 1995). These home-commuting trade-offs can have significant spatial effects on an urban region (i.e. where people work and live), therefore to plan appropriately for the future, their behaviours and patterns should be considered in urban land-use and transportation policies. Tscharaktschiew and Hirte (2010) explain that overlooking the influence of two-worker households could create an urban economy and spatial structure ill-suited for a significant part of the population.

2.3.1 Considering Angles to Capture Spatial Patterns of Two-worker Households

Much of the literature on two-worker households has been dedicated to measures that capture the spatial configuration of the home and work locations. This includes creative measures, such as the use of angles, which have often been employed for understanding residential location (Van Ommeren, 2000). Generally, there are two types of angles used throughout the existing literature: 1) the home-central business district (CBD)-workplace angle; and 2) the workplace1-home-workplace2 angle. The home-CBD-workplace angle, set out in Figure 2.1, is employed by several studies in the existing body of literature, including Curran et al. (1982) and Vandersmissen et al. (2003). Curran et al. (1982) explore the residential location decisions of two-worker households where the workers have separate employment locations – one being in the CBD and the other in a secondary employment centre. Their study developed a model in which the bid price (home location cost) is a function of both distance and the direction from the CBD. The authors also explain that a household’s willingness to pay for a location depends on its distance from both employment centres, commuting costs, wages paid to the worker, and the level of utility associated with the location. From their model, predictions are made with respect to where two-worker households will choose to locate given that work locations are in two different employment centres. Vandersmissen et al. (2003) also identify this home-CBD-workplace angle in their study, which examines spatial and social reasons for increased commuting distances over several decades in Quebec City, Canada. The authors explain the rationale of using this angle to measure the relationship between directional bias and work-trip length as follows: in a monocentric city, commuting distance should increase as the home-CBD-workplace angle increases; however, as a city evolves away from this city form, commuting time is less impacted by the home-CBD-workplace angle. This relationship is true for their study of
Quebec City, which has over time experienced a restructured transportation network and changes in home and work locations that reflect a polycentric urban form.

The use of this angle is most appropriate for a monocentric city, in which case a narrower angle is ideal as it would lead to faster travel. This is based on the theoretical assumption that it is generally faster to travel in the direction of the CBD since transportation networks are designed to access the CBD. In the context of non-monocentric cities, the angle of workplace1-home-workplace2 has been used to describe the positioning of two-worker households relative to their associated workplaces (Van Ommeren, 2000). In using this approach, acute angles (less than 90 degrees, the extreme being 0 degrees) indicate that commuters travel in similar directions, while obtuse angles (greater than 90 degrees, the extreme being 180 degrees) indicate that commuters travel in dissimilar directions.

Figure 2.1: Home-CBD-Workplace angle and Workplace1-Home-Workplace2 angle

Van Ommeren (2000) evaluates the influence of the distance between workplaces as well as the angle created at the home location as factors influencing the job and residential search behaviour of two-worker households. The author explains that in more than half of the households, the distance between the workplaces is less than 10 kilometres and in 85 percent of the households, the angle is smaller than 90 degrees. Therefore, the typical household in this study is not located in between the workplaces and instead, the wage earners travel to their work in the same
direction. The deduction here is that acute angles indicate commuters travelling in the same
directions, while obtuse angles indicate commuters travelling in the opposite directions.

2.3.2 Commuting Behaviours of Two-worker Households

There is considerable interest in two-worker households among urban economists and urban planners. Investigations to date have been motivated by attempts to understand: gender dynamics in the commuting behaviour of two-worker households; home location choices of two-worker households compared to single-worker households (Curran et al., 1982) and the excess commuting of two-worker households (White, 1988).

There is much debate in existing research around whether two-worker households commute more or less than their single-worker counterparts. Intuitively, one would expect that two-worker households commute more than one-worker households simply due to the addition of a commute trip per household. In White’s (1988) study, this is cited as one factor that would likely explain why some urban workers choose to commute more than the average minimum commuting journey length. Since workers in two-worker households must commute to two different workplaces from a single residence, it is more likely that one or both workers will choose an outward or circumferential commute, which would then lead to relatively long commute time and distance (excess commuting). Despite this intuitive reasoning, existing literature on the subject has not been conclusive on that point and many, such as Kim (1995) have reported the opposite findings.

Kim (1995) analyzes the commuting behaviour of two-worker households by accounting for the constraints they face and then calculating that individuals in two-worker households, in fact, have on average shorter commute distances than those in one-worker households. Other studies, such as Sultana (2005), make similar conclusions, which ultimately lead us to consider the reasons or factors influencing this reported travel behaviour. Kim (1995), as well as Ma and Banister (2006), make the same conclusion that two-worker households minimize commuting distance but go further to say that the commuting distances of workers within the two-worker household are complementary to one another. Plaut’s (2006) study, although focused on the differences in commuting behaviour between the individuals in a two-worker household, also makes the same conclusion.
2.3.3 Commuting Trade-offs of Two-worker Households

As identified above, there are several studies which investigate whether two-worker households commute more or less than their single worker counterparts. However, their assertions require empirical investigations of the factors that support their findings. Some research has identified the trade-offs made by individuals in two-worker households as one such explanatory factor. Trade-offs arise out of the need to accommodate the home to work trips of two individuals residing in the same location but working in potentially very different locations. Most investigations of two-worker households consider home location choice and commuting trade-offs in isolation of commuting mode choice considerations. Although some researchers take commuting mode choice into consideration, they either consider it as an exogenous factor in the analytical framework or only consider a very partial representation of commuting mode choice (Freedman and Kern, 1997). Plaut (2006) investigates the commuting distance trade-off between workers in two-worker households but considers only car users. In a recent study, Surprenant-Legault et al. (2013) consider commuting mode as an exogenous variable to the commuting distance regression model. Their study indicates that for every one percent increase in one partner’s distance, total commute distance increased by less than one percent and therefore leads to the conclusion that individuals in two-worker households are in fact trading-off commuting distance. However, the above-described scenario can also exist when households relocate in a manner which increases their total commute distance, as long as the increase in one worker’s commute is greater than the decrease in the second worker’s commute.

2.3.4 Modelling Approaches

Examples of modelling approaches in the existing literature on two-worker households is limited. In the past, empirical studies involving two-worker households have analyzed the lengths of commuting distances of both workers. Freedman and Kern (1997) is an early study in which home and work locations are examined using a discrete choice model. Their study jointly models home location and workplace locations of both workers as a function of various factors including the quality of the residential environment, wages and commuting times of both workers. Modelling approaches have since evolved to study commuting trade-offs. For instance, as previously noted, Surprenant-Legault et al. (2013) use regression modelling techniques to
examine commuting trade-offs between workers in two-worker households. In their study, commuting mode choice is used as an exogenous variable to the commuting distance regression model.

Some researchers have considered the commuting mode choices of two-worker households but without examining the commuting distance trade-offs made. Badoe (2002) presents a household-level joint commuting mode choice model for two-worker households and highlights the importance of considering a joint commuting mode choice model for multi-worker households. Badoe (2002) argues that household travel survey data used for commuting mode choices are based on sampling households, not individuals, and hence it is necessary for commuting mode choices to be modelled jointly at the household level for two-worker households. Maat and Timmermans (2009) develop discrete choice models that take into account factors that affect mode choice and car usage for single and two-worker households. Their study finds that built environment characteristics of residential neighbourhood only affects car use for single worker households, while work locations affect car usage for all commuters but especially for two-worker households.

2.3.5 Gaps in Existing Research on Two-worker Households

The above summary identifies notable gaps in the existing literature on two-worker households. Household-level commute mode choices and the home-work spatial configuration of two-worker households have not been jointly explored in empirical models. To date, these factors have been investigated in isolation; however, as commonly understood there is a two-way interaction between land-use and transportation. Therefore, jointly modelling these factors and examining the impact of commuting mode choices on land-use is necessary. Furthermore, the workplace1-home-workplace2 angle has been used in various studies to describe the positioning of two-worker households relative to workplaces and the associated general commuting patterns. The impact which transportation system changes have on this configuration have not been empirically explored.

Furthermore, the concept of commuting trade-offs within two-worker households has been explored in studies. However, there is a need to determine whether households will increase the differences in individual commutes in order to reduce total household commuting distance. Only
in this scenario, where one worker increases individual commute to allow the second worker to reduce theirs, can definitive conclusions about trade-off be made. This determination is an important consideration for integrated land-use and transportation policies.

2.4 Mobility Tool Ownership, Residential Mobility and Home Location relative to workplaces

2.4.1 Mobility Tool Ownership

For this research, mobility tool ownership considers vehicle and transit pass ownership and is an important consideration in residential mobility and home location decisions. The importance of understanding a household’s mobility tool ownership is expressed by LeRoy and Sonstelie (1983) who postulate that mode choice and the resulting commuting costs are fundamental to understanding the spatial distribution of households in an urban area.

Early studies on vehicle ownership choices developed aggregate models at the level of traffic analysis zones, regions, states or countries (Stanovnik, 1990). The use of their findings is limited since the reliance on aggregate data to explain vehicle ownership choices may not be conducive to policy analyses (Potoglou & Susilo, 2008). To overcome this limitation, behavioural models using disaggregate data are developed to examine individual or household-level vehicle choices, including the number and type of vehicles owned. These choice models consider explanatory variables such as socioeconomic factors, income, purchase price, and travel opportunities by other modes (Tardiff, 1980). The multinomial logit model of car type by Lave and Train (1979) is an example of these early behavioural models.

More recent studies indicate that the effect of income on vehicle ownership has declined as vehicles have become a necessity rather than a luxury. Nolan’s (2010) study utilizes six-year longitudinal data and finds that although higher income still appears to positively affect vehicle ownership, other household characteristics such as size and composition are more significant determinants.

Other studies explore the effects of transportation costs on vehicle ownership. For instance, Bhat and Pulugurta (1998) utilize stated preference data based on different cost schemes to develop a
multiple discrete continuous model. The model examines factors affecting household choices regarding vehicle ownership and characteristics and finds that households with longer commuting distances own more cars.

One aspect of the research conducted in this dissertation evaluates how households manipulate their methods of travel in a scenario where the cost of fuel is increasing. Several studies (Dargay, 2002; Karlaftis and Golias, 2002) provide insight on the factors influencing car ownership at the household level ranging from home and work locations, lifestyle needs, children and income. The level of car ownership is also an important consideration. Handy et al., (2005) argue that high levels of car ownership are directly tied to urban sprawl and an increased amount of car trips. These in turn impact air quality and overall health. Despite this established relationship, most studies conclude that land-use attributes are more important than travel attributes when choosing a home location. However, many of the existing studies only consider a narrow range of travel costs. Erath and Axhausen (2010) consider changes to travel costs when studying the relationship between car ownership and travel behaviour of households. Generally, this Switzerland based study finds that unusual increases to travel costs results in many choosing to reduce the amount of private vehicle travel. However, their study is based on the European context, where transit usage is much higher and there is less dependence on the automobile relative to the GTA.

2.4.2 Residential Mobility

Home relocation, or residential mobility, is an important consideration for integration land-use and transportation planning since it results in changes to the location of households throughout an urban region. The first examples of modelling residential mobility rely on the concept of residential stress (Rossi, 1955). Many of the earlier studies (such as Wolpert, 1965; Brown and Moore, 1971; Miller et al., 1987) measure residential stress as the difference between the satisfaction derived from a household’s current location and the level of satisfaction that may be attained in other potential locations. However, these earlier studies do not consider that the stressors involved in residential mobility decisions are triggered by changes to life-cycle events and other environmental forces (Rossi, 1955). Habib and Miller (2005) improve upon these earlier studies by considering these factors in measuring residential stress, such as the birth/death
of a family member, job or income changes, marital status changes, as well changes to transportation options.

Home relocation is also described by Weinberg (1979) who argues that it is a result of disequilibrium. Households choose a home location in the best available site to satisfy their needs and as such they attain equilibrium. Home relocation occurs as a result of outside shocks to the system causing disequilibrium thus households relocate to mitigate the outcome of the shocks (Weinberg, 1979). However, no studies in the North American context have investigated home relocation decisions of households in response to an outside shock to the system in the form of significantly increased travel costs. Travel cost is just one factor to consider in the decision of households to relocate. In addition to travel costs, existing research has tied housing quality and cost, as well as activity opportunities to the decision to move and to the selection of a new home location (Rossi, 1955; Alonso, 1964; Muth, 1964; Brown and Moore, 1971).

2.4.3 Home Location

As supported by numerous studies, accessibility is an important factor in home location decisions. Accessibility is typically used to identify the influence of infrastructure through some measure of access to the transportation network (Iacono et al., 2008). There are many factors other than accessibility which contribute to the home-work spatial configuration. Alonso’s (1960) theory of the urban land market suggests that different socioeconomic groups have different bid rent curves; therefore, socioeconomic factors, in particular, household income, have an important role in home location decisions. For instance, Frenkel et al. (2013) identify the primary influence of a household’s socio-economic level, housing prices and commute travel time on home location choices while also recognizing the secondary influence of lifestyle and cultural amenities. Other studies reveal the influence of life cycle factors, such as the presence of children, on a household’s home location choice (Kim et al. 2005). Varying age groups can have different preferences for home locations since household needs may vary depending on the stage of life (Morrow-Jones & Kim, 2009).

Understanding home location choices is important as it can give insight into the travel behaviours of households. For instance, Krizek (2003) finds that when households are exposed to different urban forms (i.e. when they move from one type of neighbourhood to another), they
change their travel behaviours as a result. More specifically, when households relocate to neighbourhoods that are relatively more accessible, the amount of travel, measured in vehicle miles traveled, decreases (Krizek, 2003). The relationship between the home location and level of travel is reinforced by Clark et al. (2003) who find that home location is tied to commuting distance in that both one- and two-worker households will relocate to reduce the total commute time of the workers in a household. Van Ommeren (1999) has similar findings and was able to quantify that relationship by finding that increasing commuting distance by 10 kilometres shortened the amount of time households would remain at the home location by one year. Although the above studies have identified that attributes of the home-work commute influence home location choices, further empirical investigation is needed to understand the impact of increasing commuting costs, especially in terms of the direction of home location relative to household workplaces.

2.4.4 Modelling Approaches

The use of discrete choice models for residential location analysis began with the seminal work of McFadden (1974) and McFadden (1978). There have also been numerous studies of residential location analysis that have applied discrete choice models in various contexts. For instance, there are studies examining the effects of transportation factors (Weisbrod et al., 1980) and the effects of housing, auto-ownership and mode choice (Lerman, 1976). Discrete choice models have also been used to jointly model home and workplace locations (Wadell et al., 2007).

Discrete choice models have also been applied to examine residential mobility, but there are far fewer studies in the existing literature to draw from. Eluru et al. (2009) estimate a joint model that examines the reasons for residential relocation and the duration of stay at a location. Their Switzerland-based study considers a dataset that captures information about home relocation over a 20-year period. Lee and Waddell (2010) consider residential mobility and location choice as household decisions that can be modelled together using a two-tier hierarchical nested logit formulation. Their study finds that certain household characteristics, including life stage, household composition, and housing tenure, are important in explaining the residential mobility and location choice process.
2.4.5 Gaps in Existing Research

The above literature review provides an overview of the existing literature on three important elements considered in Phase two of this research: mobility tool ownership, residential mobility and home location choice relative to work location. Rising costs of fuel and the resulting increases in commuting costs are of particular importance when evaluating mobility tool ownership choices of households in the GTA. For the most part, the urban landscape of the GTA yields high dependence on the automobile especially relative to some European cities that rely more heavily on public transit. Therefore, considering increases to fuel prices is an effective and appropriate method for evaluating the impact of changes to commuting costs on mobility tool, home relocation, and location decisions of households in the GTA. Most home location choice studies consider a narrow range of travel costs. However, only in a stated preference study, can the impacts of a wide range of travel costs be examined. Although Erath and Axhausen (2010) find that increases in travel cost do result in changes to mobility tools, it is done so in a European context. Therefore, a notable gap in existing research is the study of the interdependence of household mobility tool ownership and residential mobility in the context of rising commuting costs in a North American setting. Furthermore, the above-noted literature review cites research that explores the relationship between home location choices and attributes of the home-work commute. However, a notable gap in this area of research is the study of the effects of significant increases in commuting costs on the direction of the home location choice determined relative to present household workplaces, i.e. relocating closer to, further from, or staying in the same area as the current home location. In doing so, it is possible to test the hypothesis that increasing commuting costs may result in reverse suburbanization in which households relocate closer to workplaces to mitigate transportation costs.

2.5 Transit-Oriented Development

2.5.1 TOD Concept

TOD is an integrated approach to land-use and transportation planning and is a response to the rise in social, economic and environmental hardships brought on by decades of urban sprawl. The concept of TOD is initially introduced by Calthorpe and detailed in The Next American
Metropolis (Calthorpe, 1993). Some of Calthorpe’s main principles of TOD are to place commercial development, housing, jobs, parks and civic uses within walking distance of transit stops; create pedestrian-friendly street networks which directly connect local destinations; provide a mix of housing types, densities and costs; and encourage infill and redevelopment along transit corridors within existing neighbourhoods. According to Calthorpe’s theory, the TOD core is marked by a transit station and commercial facilities, then surrounded by high-density residential and employment uses. The radius of this area surrounding the transit station is generally equivalent to a ten-minute walking distance (i.e. 400-800m). TOD has been defined and conceptualized many times ever since Calthorpe’s original principles. Cervero et al. (2002) and Nasri and Zhang (2014) conduct reviews of how TOD has been defined over time and both determined that common elements do exist such as compact, mixed-use, pedestrian-friendly development located close to and well served by transit.

It is important to understand what TOD is meant to achieve in order to evaluate whether it has succeeded. Evans et al. (2007) summarize what the application of the TOD concept intends to achieve and finds that there is a wide range of travel and non-transportation objectives. Some of the travel-related objectives include shifting away from a reliance on park-and-ride access modes and encouraging walk access to a transit station. This also ties into the objective of reducing vehicle ownership, traffic and parking requirements. Some of the non-transportation objectives include reducing urban sprawl, reducing infrastructure costs, increasing affordable housing opportunities and improving quality of life. Nelson et al. (2001) identify variables that determine the success of a TOD at both the station-area and corridor or regional scale. At the local level, success may be affected by the street pattern, parking availability, employment and housing density, commercial mix, zoning flexibility, and self-selection in residential choice. These factors are also important at the regional level; however, other factors, such as transit quality, transit technology and government policies, play a role in TOD success. These factors for measuring TOD success can be used as variables in travel demand models. However, Nelson et al. (2001) explain that since TOD at the regional level is a relatively new concept, its impact on travel demand has not been adequately explored empirically.

Most of the previous research efforts on TOD show that good transit service is a prerequisite to establishing and maintaining successful TOD neighbourhoods. Cervero and Guerra (2011) find
that a density of at least 166 jobs and persons per acre is needed to ensure an economically viable rail transit system. A study by Faghri and Venigalla (2013) reveal that transit usage and means of travel other than the automobile are expected to be higher in a successful TOD despite the slow transition away from the auto-dependent travel patterns and high levels of automobile ownership.

The National Cooperative Highway Research Program (NCHRP) have developed a strategy to measure the success of TODs (NCHRP, 2005), which builds on the research by Cervero et al. (2004). The NCHRP’s research results in a list of 56 benefits/indicators. Their research finds the most useful indicators to be transit ridership, density, streetscape quality, number of mixed-use buildings, pedestrian friendliness, increase in land value and tax revenue, connections at the transit station, and parking.

Through the various assessments of existing TODs, it is possible to identify the significant variables that affect TOD performance. For example, Quinn (2006) evaluates the TOD established in Laguna West, California and identifies some significant issues with Calthorpe’s original TOD principles. This evaluation reveals that the Laguna West TOD ignores many important social, economic and behavioural forces that undermine the success of a TOD. This report cites Calthorpe’s theory of TOD and points out that it was largely based on the assumption that TOD would form part of a network when in reality, as in the case of Laguna West, the opportunity to plan multiple new neighbourhoods that are connected across a region is rare. Some of the impeding factors to this aspect of Calthorpe’s theory, which the Laguna West TOD ignores, are issues with land assembly and competition from conventional (auto-centric) developments in the surrounding suburban regions. The main finding of this study is that implementing only the physical design guidelines (i.e. higher density) set out in Calthorpe’s TOD theory cannot change certain behaviours, namely auto-dependence, when faced with competing social and economic demands (Quinn, 2006).

Renne (2009) evaluates the development of three neighbourhoods in the East San Francisco Bay Area, each of which are surrounding a rapid transit station. The three stations are established at the same time but developments around each of them occurred differently over time. The varying success of the three neighbourhoods is considered to be a result of their locations within the region, differences in the local real estate markets and transit accessibility (Renne, 2009).
Cervero et al. (2004) proposes several variables affecting TOD based on a study of 27 TODs in California. Employment density is found to be one of the significant variables defining the success of a TOD as it is considered an important factor influencing transit ridership rates. For example, the study finds that an increase by 100 employees per acre resulted in a 2.2 percent increase in commuter rail ridership levels (Cervero et al., 2004).

2.5.2 TOD in the Greater Toronto and Hamilton Area (GTHA)

In recent years, the Ontario legislature has made additions to the Ontario planning system, including the creation of Metrolinx, which generally evolved out of the Smart Growth movement. Smart Growth is aimed at updating land-use policies to emphasize more compact, walkable, and transit-accessible development patterns (Goetz, 2004). Several policies, including those set out in the Regional Transportation Plan (Metrolinx, 2017a), have resulted from Smart Growth. The following review of Smart Growth and the Regional Transportation Plan is especially significant for this research as they form the basis for the implementation of TOD across the GTHA.

Smart Growth is a movement within the realm of urban planning that has been garnering support since the late 1990s. It is a concept that calls for new development patterns that are more compact, transit and walking friendly, less detrimental to the environment, and demand fewer infrastructure provisions than traditional patterns of development (Filion, 2003). Traditional urban development is characterized by low densities, isolation of land-uses and an auto-centric lifestyle, which has prevailed since World War Two. This urban development pattern is targeted by the Smart Growth because of its adverse consequences, including air pollution and greenhouse gases; degradation of the quality of life due to traffic congestion and increased time spent in the automobile; high costs of providing and maintaining infrastructure; and the loss of arable and natural land (Filion, 2003). This movement has reached the Ontario planning system and is reflected in local, regional and provincial policies, including The Big Move.

In 2006, the Province of Ontario passed the Metrolinx Act, under which the agency Metrolinx is established. The purpose of this agency is to coordinate and integrate all modes of transportation in the Greater Toronto and Hamilton Area (GTHA) (Metrolinx, 2008a). Working towards the development and implementation of a regionally integrated transportation system, in 2008
Metrolinx launched the first regional transportation plan entitled The Big Move (Metrolinx, 2008). That plan has been updated and the new Regional Transportation Plan (Metrolinx, 2017a) ensures transportation priorities of the GTHA are maintained and it also looks forward to 2041. The concept of TOD is reflected in Metrolinx policies, namely in their Mobility Hub Guidelines (Metrolinx, 2011). A Mobility Hub consists of a transit station and its surrounding area, which is identified as an approximate 800-metre radius that can be comfortably accessed by walking. Furthermore, Mobility Hubs are to have an intensive concentration of employment, residential, commercial and recreational uses. The Mobility Hub concept is a long-term plan for many of the GO Transit rail station areas in the GTHA as they currently only offer parking facilities and low-density land-uses, typical of the suburban regions surrounding the City of Toronto where they are located (Metrolinx, 2011).

In addition to the Mobility Hub concept, TOD policies also have a substantive influence on certain development projects throughout Canada. The Canadian Mortgage and Housing Corporation (CMHC) identify and review recent examples of TOD, including two in the GTHA (CMHC, 2009). Port Credit Village is a TOD centred around a GO Transit rail station in the City of Mississauga, which is located in the GTHA (in the Regional Municipality of Peel). The GO Transit rail station at the centre of this TOD has been in operation for several years and the surrounding areas have been intensifying over time. Port Credit Village is comprised of a mix of uses including low and mid-rise residential, office and retail. There is an excellent pedestrian connection to the GO Transit rail station with landscaped paths, sidewalks and open spaces. From its review of Port Credit Village and several other TODs, CMHC concludes that since the design and development of the transit station are completed prior to the development of the surrounding neighbourhood, there is often a disconnect and lack of coordinated design between them. That coordination is essential to establishing convenient and attractive pedestrian connections to the station (CMHC, 2009).

2.5.3 Modelling Approaches

The TCRP (Cervero and Arrington, 2008) identifies the effects of TOD on housing, parking and travel by studying the impacts of reducing residential parking ratios given various densities on an eight-acre TOD. To better understand the nature of vehicle trip generation for TOD housing
projects, linear regression models are developed to explore the relationship between trip generation and various explanatory variables. In their study, TOD trip generation rates are examined as a function of 1) distance to CBD, 2) distance of TOD to the station, 3) residential densities around the station, and 4) parking provisions.

A study by Austin et al. (2010) examines 3,760 existing transit stations across the United States and develops linear regression models to describe the relationship between three dependent variables (automobile ownership, automobile use, and transit use) and independent socio-demographic and land use variables, including household income; size of household; number of commuters in household; journey to work time for transit users and non-transit users; residential density; block size; accessibility to transit and employment areas. The key finding of this study is that the highest instance of transit mode share for work trips is found to be primarily correlated with the average residential densities of TOD zones and lower rates of automobile ownership per household.

While trip generation models can predict aggregate ridership demand, it is also possible to develop discrete choice models to predict individuals’ likelihood of taking transit as a function of characteristics of TOD. A study by Kamruzzaman et al. (2014) utilizes data from census collection districts (CCDs) in Brisbane, Australia, which are then grouped into different categories based on TOD measures across six different indicators. Those six indicators include the density of residences and jobs, mix of land-uses, density of intersections and cul-de-sacs, and modal access for public transportation. CCDs are grouped into four categories of TOD, including those that are primarily surrounded by residential uses, those performing as an activity centre, those with TOD potential and those which are not likely to succeed or have potential to be a TOD. For each of the four groups, a multinomial logistic regression model is estimated to capture the mode choice behaviour of individuals living in these areas. The results conclude that people who reside in areas not likely to be a TOD are less likely to take public transit.

A study by Nasri and Zhang (2014) examines the impacts of TOD on the travel behaviour of residents in the metropolitan areas of Washington, D.C. and Baltimore. A multi-level, mixed-effects regression analysis is used to model vehicle miles traveled (VMT) as a function of households’ socioeconomic variables, land-use variables, and transit accessibility. A dummy
variable is used in the analysis to represent whether the traffic analysis zone is located in a TOD or not. The modelling results indicate that higher bus stop density and living in TOD has a negative association with VMT. Another study by Chan and Miranda-Moreno (2013) uses trip production and attraction models at the station-level of the metro network in Montreal, Quebec, to examine transit ridership and its influencing factors such as population density, average income, connectivity of bus service, the frequency of service, distance to the central station, etc. Overall the results suggest that densification, land-use diversity and transit connectivity have a positive association with transit ridership. The existing empirical research related to TOD is lacking. The above summarizes the extent of the major empirical contributions on this topic, which are primarily limited to regression models that do not capture travel behavior at a disaggregate level. A thorough analysis of travel behaviour in the context of TOD requires the application of discrete choice models using stated preference data that capture conditions of TOD that may not presently exist.

2.5.4 Stated Preference Data

This research uses stated preference (SP) data to examine the choice behaviour of individuals that live in the proximity of regional transit stations. SP data are preferred for this research over revealed preference (RP) data because of its ability to find relationships and explain non-existing situations or choices and their covariates. As Ben-Akiva (1994) explains, SP data are based on respondents’ intentions or choices within some hypothetical scenario. In experiments using SP data, a number of choice scenarios are presented to a respondent and each scenario describes alternative choices. The alternative choices will have a set of predefined attributes that can take a range of pre-selected levels.

SP data have several advantages, especially compared to RP data, and are therefore often used in market research experiments. Those advantages over RP data include using pre-specified choice sets and an extended range of attributes, avoiding multicollinearity of attributes, incorporating attributes that are not easily quantified (i.e. safety, reliability, and availability) and eliminating measurement errors in attributes (Morikawa, 1989).

Conversely, SP data have some negative aspects, which researchers have tried to account for. Unlike RP data, SP data are not based on actual market behaviour and therefore the validity and
accuracy of its predictions of actual market behaviour are often challenged. Bias is also a
potential issue with SP data as the context and format of the hypothetical scenario presented can
affect the respondents’ choices (Ben-Akiva, 1994). To account for these negative aspects, this
research combines both RP and SP data. This has been an effective method used in previous
research as it addresses the validity issue with SP data and improves the accuracy of the
parameter estimates. Although this research combines both RP and SP data, it is acknowledged
that utilizing SP data still presents challenges. For instance, presenting multiple SP scenarios
consisting of several attributes may be too onerous for respondents’ consideration and may elicit
unrealistic responses. Accordingly, the survey designed for this research limits the number of
attributes presented in the SP scenario to prevent overburdening respondents while still
collecting critical information required for a behavioural analysis.

In the field of transportation planning, data that shed light on how individuals will act in a future
setting is especially important when planning for future demand. Louviere et al. (2000) recognize
the strength of SP data in the field of transportation because of its ability to determine the
influence of independent variables on an observed outcome. For instance, certain factors that
affect transportation demand can change rapidly and if not appropriately planned for,
modifications to the physical environment (i.e. infrastructure) can lag behind and fail to meet the
altered demand.

2.5.5 Gaps in Existing Research on Transit-Oriented Development

The literature on TOD is extensive, however, there are major gaps in the empirical efforts aimed
at understanding the impacts of TOD. The existing research indicates that some of the
overarching goals of TOD is to reduce auto-dependence and improve active transportation.
Therefore, it is important to study the factors that influence transit ridership, especially with walk
as the access/egress mode to the main transit station of a TOD. There are existing empirical
studies that examine variables associated with transit ridership, but most of these studies use
regression models which cannot capture travel choice behaviour at a disaggregate level. A
disaggregate level of analysis is required to identify specific factors and attributes of TOD that
may encourage or hinder individual mode choices of active transportation modes. Doing this
requires the application of discrete choice models and SP data to represent hypothetical TOD
conditions that may not presently exist. This type of empirical research is highly critical for planning agencies such as Metrolinx who wish explore the potential of achieving TOD with high levels of active transportation surrounding their stations.

2.6 Chapter Summary

This chapter presented a review of the literature that is relevant to each of the three contexts through which this research examines land-use and transportation interactions. Within the context of two-worker households, a review is provided of the literature on the use of angles to capture spatial patterns, commuting behaviours and commuting trade-offs of two-worker households. Within the context of rising commuting costs, a review is provided of the literature on mobility tool ownership, residential mobility and home location decisions. Finally, within the context of TOD, a review is provided of the literature on the concept of TOD, planning framework for TOD in the GTHA, modelling approaches, and the use of SP data. Despite the numerous works in these areas, there are notable gaps which this research aims to address. The motivation for this research is to improve on the understanding of land-use and transportation interactions using these contexts and to better inform integrated land-use and transportation policies.
CHAPTER 3

3 Conceptual Framework

3.1 Chapter Overview

This chapter sets out the conceptual framework for analyzing land-use and transportation interactions in the contexts of two-worker households, rising commuting costs, and TOD, respectively. Section 3.2 introduces our motivation for this research and the rationale for the framework. Section 3.3 presents the overall framework and provides a description of the phases within the framework. Section 3.4 provides a detailed description of each phase of the framework, as well as the steps within those phases. Finally, Section 3.5 summarizes the key points of this chapter.

3.2 Introduction

The two-way interaction between land-use and transportation systems is manifested in several ways throughout the urban environment (Wegener and Furst, 1999). We can conceptualize about the effects of these interactions on the basis of existing studies. For example, the post-war boom in highway construction and the large-scale use of the private automobile led to the development of suburban sprawl. This, in turn, led to deplorable traffic conditions and air pollution. However, we do not yet possess a detailed understanding nor the analytical techniques to capture the full impact of these dynamic interactions, especially the feedback effects from transportation to land-use. A proper understanding of the linkage between these two systems is important because it is required to predict future transportation demand, as well as to inform integrated land-use and transportation planning. An integrated planning approach is required to shape our cities in a manner that is socially, economically and environmentally sustainable. More specifically, objectives of this approach which are related to this research include: reducing the need and length of trips; and increasing use of public transit and active transportation. Figure 3.1 captures the motivation for this research as well as the rationale for the framework. It identifies land-use
and transportation interactions and the three contexts of those interactions which this research focusses on.

![Figure 3.1: Research motivation and rationale for the conceptual framework](image)

The motivation for this research is to improve our understanding of land-use and transportation interactions by conducting empirical studies to capture household behaviour in response to changes in the transport system and urban environment. An improved understanding of these interactions allows us to better establish integrated land-use and transportation policies, which when implemented will contribute to socially, economically, and environmentally sustainable growth.

### 3.3 Conceptual Framework

As set out in Figure 3.2, the conceptual framework for this research consists of three contexts under which we examine the land-use and transportation interaction. These include: 1) two-worker households; 2) rising commuting costs; and 3) TOD. In the first context, the research uses empirical methods to investigate the factors affecting the home-work spatial configuration of two-worker households. These factors include commuting modal accessibility and the commuting trade-offs made between individuals in these households. In conducting these analyses, we are able to study the influence of transportation system factors on the land-use in respect of two-worker households.
Another aspect of the transportation system is the cost associated with commuting from home to work. As such, in the second context, the research uses empirical models to examine household choices under the scenario of rising transportation costs. More specifically, we examine home relocation in conjunction with mobility tool ownership and home location relative to the existing workplace. By using the context of rising commuting costs, we are able to examine the influence of a transportation system factor on land-use, in particular on households’ home relocation and home location choices.

Acknowledging that there is a two-way interaction, in the third context, we examine the influence of a particular type of land-use on travel choices. More specifically, we examine those choices in the context of TOD. Initially, we examine transit ridership with walk access and walk egress as an outcome of TOD. Due to the lack of empirical research in travel behavior associated with TOD, the next step includes the planning, design and implementation of the Living Near Transit Survey which captures the influence of TOD characteristics on travel behaviour. Next, the research uses behavioural models based on the survey data to examine the influence of TOD on travel mode choice and transit station access choice.

This research focusses on these three contexts, even though there are potentially several different ways in which the two systems interact, because they can represent some aspect of sustainable development. The described research approach is different than frameworks for integrated land-use models, which are powerful tools in their own right. According to Wegener and Fuerst (1999), empirical studies on land-use and transportation interaction examine the effects of land-use policies on transportation and vice versa. On the other hand, integrated models of land-use and transportation interaction are used to simulate human decision making and its consequences over a period of time in an urban area. The theme of this research is focused on the former topic of empirical studies on land-use and transportation interaction. However, it may be possible to use some of this research’s contributions towards the enhancement of integrated land-use transportation models. The different contexts used in this study are useful tools to assess important integrated land-use and transportation policies.
3.4 Details of Framework Components under Investigation

The preceding section presented the conceptual framework for this research and described how the different phases of the framework are interconnected. This section provides a more detailed
description of each phase of the conceptual framework, including the steps within those phases. The first, second, and third phases of the framework correspond to the contexts of two-worker households, rising commuting costs, and TOD, respectively.

3.4.1 Two-worker Households

In the first phase of our research, we focus on the context of two-worker households. Understanding two-worker households is important for planning for future travel demand as some researchers estimate that the number of two-worker households is growing and will make up a significant share of urban residents in the near future (White 1988; Hotchkiss and White 1993; and Clark et al. 2003). This portion of the urban population is unique in that they face dual constraints due to the two work locations when making home location and commuting choices. These choices can have significant spatial effects on an urban region (i.e. where people work and live), therefore to plan appropriately for the future their decisions should be considered in urban land use and transportation policies.

Figure 3.3 presents the framework for analyzing land-use and transportation interactions in the context of two-worker households. The primary reason for developing this conceptual framework as such is to fill some of the gaps in the literature of two-worker households. In particular, this framework emphasizes the understanding of factors that influence the home-work spatial configuration of these households. This configuration has two attributes: 1) the total household commute distance, and 2) the angle between the workplaces of the commuters measured at their common home location. As previously noted, existing research has examined many aspects of two-worker households, including geometric measures to capture the home-work spatial configuration and their commuting distance relative to single worker households. However, the role of commuting modal accessibility as it relates to the spatial configuration has not been explored. In this research, commuting modal accessibility is defined as an accessibility measure that considers the expected maximum utility (EMU) derived from all modes of transportation for the two workers.

For this reason, the scope of research for the first step in the detailed framework for Phase one includes the development of joint econometric models, which study the factors that influence the spatial configuration of two-worker households. In particular, the models capture the influence of
endogenous commuting modal accessibility in defining household-level total commuting distance and the angle between the two workplaces at the home location. Two types of models are to be estimated: 1) A non-mixed model that considers IID assumptions for the mode choice random utility component; and 2) a mixed model that considers separate variances for different modes’ random utility functions. Data for these models are obtained from the 2011 household travel survey data for the National Capital Region.

The intent of this first step in our research is to explore a specific land-use and transportation system interaction by establishing a connection between modal accessibility and the geometrical, spatial distribution of households and jobs. We aim to explore factors, in particular, modal accessibility, that prevent two-worker households from achieving their optimal home location. Strictly from a physical distance standpoint, the optimal home location for these households is on a straight line connecting the two workplaces, resulting in a 180-degree angle and a short commute distance. Understanding this particular interaction can assist in achieving an overarching goal of integrated land-use and transportation planning, which is to bring homes and jobs closer together, thereby reducing the length of trips. For two-worker households, this would mean reducing the combined commuting length of both partners, which we hypothesize occurs at the above-described optimal home location.

Another overarching goal of integrated land-use and transportation planning is achieving a jobs-housing balance, which occurs when there is heterogeneity between employment locations and home location of workers in a given catchment area (Horner and Murray, 2003). Jobs-housing balance is also described as a balanced community where residents can both live and work or an equal distribution of employment and workers (Giuliano, 1991). Some research has identified the presence of two-worker households as an obstacle to achieving jobs-housing balance since these households are unable to locate near both workplaces (Giuliano, 1991; Giuliano and Small, 1993; Levine, 1998; Dieleman et al., 2002). Therefore, the second step in this phase of research examines commuting trade-offs, which occurs when a home relocation results in one worker incurring a higher commute distance so that the second worker may work closer to their home while reducing the total household commute distance. If two-worker households are found to make commuting trade-offs, the assertion in existing literature that jobs-housing balance is not possible due the presence of two-worker households may be challenged. If trade-offs are made
and as a result one worker works closer to their home location, two-worker households may in fact contribute to achieving some level of jobs-housing balance in a given area.

To test this, the scope of research for step two of Phase one includes estimating two models of household level commute distance. These include a Cobb-Douglas log-linear regression model and a multi-level random intercept model. The model specification includes the variables which describe the spatial configuration of two-worker households as well as a unique variable, namely the difference between individual commute distances, which are used to make inferences about commuting trade-offs. Data used for these models are obtained from a stated adaptation survey entitled Car and Home Ownership Decisions in the Face of Increasing Commuting Costs (CHOICE) (Papaioannou and Habib, 2014).

In summary, the first phase of this research as outlined in Figure 3.3, focuses on a segment of the population facing a unique constraint of two workplace locations. The research in this phase which examines the effects of commuting modal accessibility and commuting trade-offs on the home-work spatial configuration reveals important findings of the interactions between land-use and transportation.
3.4.2 Rising Commuting Costs

The second phase of the research examines household choices related to home relocation, mobility tool ownership and home location, in the context of rising commuting costs. Transportation cost is an important aspect of the transportation system that greatly affects household location choices which in turn affect land-use configuration. Although the existing research has established the importance of this factor, most studies only consider a narrow range of travel costs. Conversely, this phase of the research considers a broad range of commuting costs to examine household choices. This allows the research to capture a wider spectrum of impacts associated with this attribute of the transportation system.
This phase of the research considers substantial increases to commuting costs which may result from potential increases in gasoline prices at local pumps. The price of crude oil, as established in the global market, has the greatest impact on local gasoline prices (Statistics Canada, 2012). The increase in international crude oil price from $44.08/barrel in January 2005 to $142.46/barrel in July 2008 spawned an interest to study the impacts of rising oil prices on urban areas (Dodson and Sipe, 2007; Krumdiek, 2007; Krumdiek et al., 2010; Akbari and Habib, 2014). It is difficult to predict the future price of international oil since there are numerous influencing factors. These include fundamental factors such as supply and demand, but also non-fundamental factors such as geopolitical tensions and potential disruptions to supply (Newman, 2008). Other factors potentially affecting future oil prices include the depth of giant petroleum discoveries in the last two decades assisted by technological advances that have facilitated this type of exploration (Railsback, 2013). Irrespective of the debate concerning future oil prices, our research considers rising commuting costs as it provides a useful context to study household decisions affecting land-use configuration.

Figure 3.4 presents the framework for analyzing land-use and transportation interactions in the context of rising commuting costs. The primary reason for developing this conceptual framework as such is to fill some of the gaps in the literature that is relevant to this study. It is intuitive that households may react to issues concerning land-use or transportation (i.e. increasing transportation costs) with a combined adjustment to their medium-term (mobility tools) and long-term (home location) behaviours. For instance, Pinjari et al. (2011) explain that households make decisions concerning land-use and transportation as part of an overall lifestyle package rather than a series of independent sequential decisions.

The scope of research for step one of this framework includes a combined discrete choice model that considers the household choice to relocate and/or adjust their mobility tool ownership in the face of rising transportation costs. By jointly considering these two types of choices, this model examines the interaction between mobility tool ownership changes and home relocation choice.

Furthermore, travel costs are an important consideration in home to work commute and is, therefore, a factor in home location choices. Boarnet (2011) explains the influence of travel costs on bringing origins and destinations closer together through compact development. Furthermore,
it is concluded that research on land-use and transportation has not sufficiently explored the various choices that affect the built environment and researchers could start by considering the workplace location in their location choice models. Therefore, the scope of research for step two of this framework includes a discrete choice model that considers the direction of home location choice relative to workplace location, i.e. moving closer to the workplace, further from the workplace, or staying in the same city as the workplace. Framing the research in this way allows for the examination of whether transportation costs induce households to relocate closer to their workplace to mitigate costs. Data for both models in this phase of the research are obtained from the CHOICE survey which was collected from cross-regional commuting households in the GTA.

In summary, the second phase of this research, as outlined in Figure 3.4, focusses on household choices that affect land-use configuration in the face of significant increases in commuting costs. The intent of this research is to test whether significant increases in commuting costs would induce home relocation in a manner that brings origins and destinations closer together.

Figure 3.4: Detailed framework for rising transportation costs
3.4.3 Transit Oriented Development

The third phase of the research focusses on the influence of TOD on travel choices. TOD is a design concept that calls for mixed-use, compact and pedestrian-friendly urban development that is oriented towards transit use. Using integrated aspects of land-use and transportation, TOD seeks to mitigate the challenges brought on by decades of urban sprawl. Two key principles of TOD are reducing the reliance on the automobile and encouraging the use of public transit and active transportation modes. Although there is extensive literature on TOD, empirical research on this topic is lacking. Therefore, this phase of the research develops empirical models to study the impact of TOD on transportation choices. The findings of this study are critical to the regional transit authority in the GTHA, who have expressed an interest in assessing the potential for TOD around their current and future rail stations.

Figure 3.5 presents the framework for analyzing land-use and transportation interactions in the context of TOD. The primary reason for developing this conceptual framework as such is to fill some of the gaps in the literature of TOD. In particular, this framework emphasizes the understanding of TOD factors that influence travel behaviour. Although studies have examined rail ridership using regression models, there is no research that isolates rail ridership for trips that started or ended in walking. The understanding of factors that influence rail ridership with walk as the access and egress mode is relevant to TOD and is a high priority for the regional transit authority in the GTHA. Therefore, the scope of research for the first step in the detailed framework for Phase three includes the development of rail ridership models for trips that started or ended in walking. The data used for this step was extracted from a rail passenger survey of passengers using the GO Transit rail system in the GTHA.

The models in step one identified station-level attributes and characteristics of the urban environment surrounding the rail station that influence rail ridership with walk access and egress. Although these models are useful, they consider aggregate trip data. A more behavioural analysis is required to identify specific factors associated with TOD that influence travel choices. Therefore, scope of research for the second step in the detailed framework for Phase three includes the development of the Living Near Transit survey, which is designed to collect disaggregate SP data from households who reside within a walking catchment area of GO Transit.
rail stations. Respondents are requested to select mode choices under various SP scenarios that mimic TOD. The intent of this survey is to collect disaggregated data which can be used for behavioural analyses.

The collected data from the Living Near Transit survey is used to develop a random parameters logit model in the third step of Phase three of the detailed framework. The model is a discrete choice model that considers main modes and access modes. Main modes are defined as the primary mode used for the majority of the work trip, while the access mode is the mode of transportation used to access the GO Transit rail station at the start of the work trip. The model provides insights into specific demographic and TOD factors that influence mode choice behaviour. Particularly important are the factors that encourage or hinder the choice for active transportation access modes, which is a high priority consideration for Metrolinx. The intent of this analysis is to advance the understanding of TOD in relation to travel demand and to use the modelling results to guide the design and implementation of TOD in the future.

In summary, the third phase of this research, as outlined in Figure 3.5, focusses on TOD, which is a popular design concept aimed at mitigating environmental impacts associated with urban sprawl. The research in this phase consists of a survey design and empirical models which aim to increase the understanding of factors associated with TOD that influence travel choices.
Figure 3.5: Detailed framework for TOD
3.5 Chapter Summary

This chapter presented a conceptual framework that is designed to advance the current state of understanding of land-use and transportation interactions. To achieve the objectives of this research, empirical studies are conducted in the contexts of two-worker households, rising transportation costs and TOD. A detailed framework is provided for each of the above-noted contexts which outlines the rationale for the empirical studies conducted in the research. A summary of the land-use and transportation relationships and the corresponding variables within each context is set out in Figure 3.6.

The aim of the conceptual framework is to fill some of the gaps in the relevant literature. In Phase one, the conceptual framework includes conducting empirical models to examine the influence of commuting modal accessibility and commuting trade-offs (both of which are closely related to the transportation system) on the home-work spatial configuration of two-worker households. In Phase two, the conceptual framework includes developing discrete choice models to examine household choices affecting land-use configuration in the context of rising transportation costs (a factor associated with the transportation system). In Phase three, the conceptual framework includes developing empirical models that consider rail ridership with walk access/egress as a function of station-level attributes and characteristics of the surrounding environment. This is followed by the design of the Living Near Transit survey which collects disaggregate household-level data from households residing within the walking catchment area of GO Transit rail stations. The conceptual framework concludes with the final step in Phase three, which is the development of a mode choice model, using the collected data, to examine specific demographic and TOD factors that encourage or deter the use of various travel modes.
Figure 3.6: Variables considered in the land-use/transportation relationships
CHAPTER 4

4 Relationship between Modal Accessibility and the Home-Work Spatial Configuration of Two-worker Households

4.1 Chapter Overview

The first step of phase one of this research is presented in this chapter. Phase one focuses on the context of two-worker households. The first step investigates the relationship between commuting modal accessibility and the home-work spatial configuration (HWSC) of two-worker households. Joint econometric models are developed to capture the influence of endogenous commuting modal accessibility in defining household-level total commuting distance and the angle between the two workplaces at the home location. Data for these models are obtained from the 2011 household travel survey data for the National Capital Region (NCR). This chapter is organized into the following sections: Section 4.2 briefly introduces the motivation and research design for this study. Section 4.3 provides an overview of the study area and data used in modelling. Section 4.4 outlines the econometric modelling framework, and Section 4.5 presents the modelling results. Section 4.6 discusses the policy implications arising from the results. A summary of the chapter is presented in Section 4.7.

4.2 Introduction

4.2.1 Motivation

Two-worker households have been increasing in number and are a unique portion of the population. Statistics Canada reports that the percentage of households with two employed parents has risen from 36 to 69 percent over the last 40 years (from 1976 to 2016) (Statistics Canada, 2016). Two-worker households face the dual constraint of two work locations, which can have significant spatial implications for their home and work location patterns (the HWSC). The HWSC of urban residents fundamentally defines the spatial structure of any city, and an increase in two-worker households may shape the urban economy and spatial structure very
differently than expected if urban land use and transportation policies overlook the growing proportion of two-worker households (Tscharaktschiew and Hirte, 2010). Therefore, a proper understanding of the factors that influence their HWSC is highly desirable for integrated land-use and transportation planning. Although two-worker households have received attention from researchers in the past two decades, many questions related to the factors that influence their HWSC have not been explored empirically. This step of the research uses joint econometric models to investigate the impact of commuting modal accessibility on the HWSC in the NCR.

4.2.2 Research Design

The HWSC, as depicted in Figure 4.1, is defined by: a) the total home to work commuting distance of both workers (herein referred to as household commuting distance); and b) the angle between the two work locations measured from their common home location (herein referred to as workplace1-home-workplace2 or angle). Any location on a line connecting and in between the two work locations results in a 180-degree angle and the shortest possible household commuting distance, provided that the two work locations are fixed. Therefore, home locations that yield a larger (or wider) angle are considered more optimally located because they result in shorter household commuting distance. Considering only household commuting distance cannot provide this insight on home location optimality. Given the two fixed work locations, it is angle that provides an indication of whether the HWSC is optimal from the perspective of reduced commuting distances. One can object that distance minimization is not the only factor that households consider. Other important factors include real estate prices, availability of housing stock, neighbourhood characteristics, and lifestyle preferences, all of which may not be optimal at these locations from the household’s perspective. The importance of these factors is acknowledged and once these are controlled for a general tendency towards distance minimization should be observed. As such the first objective of this research design is to use empirical analyses to explore the HWSC by examining the influence of commuting modal accessibility on household commuting distance and angle. Commuting modal accessibility is defined as an accessibility measure that considers the expected maximum utility (EMU) derived from all modes of transportation for the two workers.
The second objective of this research design is to empirically examine the correlation between household commuting distance and angle and to make inferences about urban sprawl. In order to make those inferences, this research considers the following a-priori hypotheses. Urban areas that include a high number of two-worker households with workers generally travelling in the same direction (thereby creating an acute angle) may be an indication that there is a lack of job centres in close proximity to these households. For instance, in sprawling urban regions of North America, there is typically a dominant CBD that exerts considerable attraction on households residing in suburban peripheral areas. The CBD contains a high concentration of employment opportunities while the suburban areas are dominated by residential uses. Accordingly, workers from two-worker households residing in suburban areas are likely travelling in the same direction to the CBD for work, thus creating an acute angle. In this scenario, which is characteristic of sprawling urban regions, it is reasonable to expect an inverse relationship between household commute distance and angle (as depicted in Figure 4.1). Conversely, urban
areas with a high number of two-worker households with workers travelling in dissimilar directions (thereby creating an obtuse angle) may be an indication that these households are more centrally located and in close proximity to job centres. Since there is typically a mix of employment opportunities distributed throughout job centres, there is a greater likelihood that both workers from centrally located households are travelling in dissimilar directions, rather than being drawn to one area of concentrated employment uses, thus creating an obtuse angle.

4.3 Study Area and Data

The first step of phase one of this research examines the NCR of Canada, which is composed of the Ottawa-Gatineau metropolitan region that covers 4,715 square kilometres across two provinces, Ontario and Quebec. As the political centre of Canada, the NCR has the highest concentration of government workers in the country and has experienced rapid jobs and housing growth (Armstrong and Khan, 2004). In 2011, the total population of the study area was approximately 1.23 million in 500,000 households. The transportation infrastructure includes more than five major highways, an extensive road network and public transit system. The Ontario portion of the NCR is serviced by an urban transit service, OC Transpo, which consists of a regular bus network and a rapid transit system (grade-separated and dedicated bus lanes). The Quebec portion of the NCR is serviced by a regular bus network system, Société de transport de l'Outaouais. The NCR is divided into 673 traffic zones (TAZ).

An origin-destination (O-D) household travel survey is conducted in these TAZs. The latest O-D survey was conducted in 2011 for five percent of households in the NCR. This sample is considered to be representative of the population and is used in this study. The TRANS Committee (2013) of the NCR has a detailed report of the 2011 O-D survey. A total of 25,373 households were surveyed, of which 5,923 are two-worker households, representing 23 percent of all households in the study area. The percentage of two-worker households in the NCR is higher than that of Montreal and lower than that of Toronto. However, approximately 60 percent of the sample of two-worker households (a total of 3,553) have reported both workers’ commuting trips in the trip diaries. This subset of 3,553 households is used for the empirical investigation in this study. After cleaning the data for missing values of key household and
personal attributes, a sample consisting of 3,225 two-worker households is retained for empirical investigation.

It is widely recognized that mode choice behaviour is closely related to trip chaining behaviour, which includes activities that travellers take part in before and after work. This close relationship between mode choice and trip chaining behaviour has caused research in mode choice behaviour to shift from trip based to a tour-based approach in activity-based travel demand modelling (Ben-Akiva et al, 1998). However, since this step of the research focuses on exploring the spatial patterns of commuting trips, and the factors that affect the HWSC, we do not consider the rest of the daily trip chain. Furthermore, since we are modelling commuting mode choices, we consider the subset of households that observed commuting trips in the trip diary dataset.

The dataset retained from the O-D survey contains household characteristics, personal characteristics and commuting information. We supplement this data with transportation level-of-service attributes and land-use attributes. Since the spatial unit of analysis is the TAZ, *household commuting distance* and *angle* is calculated at the zone centroid. This data aggregation may result in some discrepancy between actual home and work locations and the zone centroid. Transportation level-of-service attributes are generated by a TRANS model calibrated with the 2011 O-D survey. The TRANS model is developed in the EMME traffic assignment software for transportation planning activities in the NCR (TRANS Committee, 2013). Table 4.1 presents a numerical summary of certain key variables used in the models. The definitions of all variables and the discussion of results is set out in Section 4.5.
As indicated previously, the HWSC is defined by two variables:

1) **Household commuting distance**; and
2) **Angle**

*Household commuting distance* is obtained from the EMME generated model, while *angle* is calculated for each two-worker household. Figure 4.2 presents the zonal average *household commuting distance* and *angle*. As expected, *household commuting distance* and *angle* appear to have an inverse relationship (i.e. high *household commuting distances* associated with small *angles*). Therefore, we speculate that there is some correlation between these two variables of the HWSC, which may be a function of different spatial interaction variables.

As noted in Table 4.1, the maximum and mean values recorded for *angle* are 114.6 and 36.8 degrees respectively. These values are comparatively lower than those reported by Surprenant-Legault et al. (2013) in their Montreal-based study. The smaller angles recorded in our study may be the result of the sprawling urban environment of the NCR and its comparatively lacking...
public transportation. These factors may therefore result in the inability of households to optimally locate their homes close to their workplaces, resulting in the narrower angle.
Figure 4.2: Zonal average household commuting distance and angle
4.4 Econometric Modelling Framework

The first step in phase one of this research proposes a joint econometric modelling structure for household-level commuting mode choices, *household commuting distance*, and *angle*. This model captures the influence of endogenous commuting modal accessibility in defining *household commuting distance* and *angle*, while also considering the direct correlation between these two attributes of the HWSC. This correlation is expressed as a function of different spatial interaction variables. Spatial interaction variables are defined by interacting household attributes (i.e. dwelling type, household income, etc.) with *household commuting distance*. The joint econometric modelling structure has three components:

1. Commuting mode choices of both workers;
2. *Household commuting distance*; and
3. *Angle*.

In order to determine the commuting mode choices, households are first divided into three categories based on their household auto ownership level:

1. No-car households;
2. Car-sufficient households (number of cars is more than or equal to the number of workers with a driver’s license); and
3. Car-deficient households (one car but two workers with a driver’s license).

For no-car and car-sufficient households, the household-level commuting mode choices are comprised of two-mode choice models, one for each of the two commuters. However, for car-deficient households, an additional car allocation model is necessary to allocate the sole car to one of the two workers.
Figure 4.3: Schematic of joint econometric modelling structure

Figure 4.3 presents the schematic of the joint econometric modelling structure. Among the three components of the joint model, mode choice and car allocation models are discrete choice models and are therefore modelled using an indirect utility-based approach. Conversely, household commuting distance and angle are continuous numbers and we, therefore, consider a direct utility-based approach to be more appropriate for these components. For the discrete choice components, we use the random utility maximization (RUM) approach, where:

1. The commuting mode choices of two workers are defined by two random utility functions: \( U_{\text{commute1}} \) and \( U_{\text{commute2}} \)
2. The household-level car allocation choice for car-deficient households is defined by one random utility function: \( U_{\text{allocate}} \)
All random utility functions are specified to be composed of systematic utility components ($V_{\text{commute1}}$ and $V_{\text{commute2}}$ for the commuter-specific mode choice, and $V_{\text{allocate}}$ for the car allocation choice at the household level) and random utility components ($\varepsilon_{\text{commute1}}$ and $\varepsilon_{\text{commute2}}$ for the commuter-specific mode choice, and $\varepsilon_{\text{allocate}}$ for the household-level car allocation choice). Each systematic utility function has the linear-in-parameter functional forms of variables and corresponding coefficients. To be generic in the formulation, we do not differentiate between the two workers in terms of any sort of hierarchy or role in the household (and we do not have this type of information in the dataset). Rather, we identify the two commuters in each household as commuter 1 and commuter 2. Equations 1, 2 and 3 present these specifications:

\[
U_{\text{allocate}} = V_{\text{allocate}} + \varepsilon_{\text{allocate}} = \sum_{\text{allocate}} \gamma y + \varepsilon_{\text{allocate}} \tag{1}
\]

\[
U_{\text{commute1}} = V_{\text{commute1}} + \varepsilon_{\text{commute1}} = \sum (\beta x)_{\text{commute1}} + \varepsilon_{\text{commute1}} \tag{2}
\]

\[
U_{\text{commute2}} = V_{\text{commute2}} + \varepsilon_{\text{commute2}} = \sum (\beta x)_{\text{commute2}} + \varepsilon_{\text{commute2}} \tag{3}
\]

Here, $y$ and $x$ refer to the sets of variables influencing car allocation and commuting mode choice. $\gamma$ and $\beta$ refer to the vector of coefficients corresponding to variable sets $y$ and $x$.

Considering the choice hierarchy, it is logical that each commuter’s mode choice influences household-level car allocation for car-deficient households. Household-level car ownership systematically determines the need for car allocation to individual commuters, and car availability to individual commuters systematically defines the choice set for commuting mode choices of the commuters. In the RUM framework, a generalized modelling framework is proposed that can capture three possible household types. For example:

- For car-deficient households of a specific category (one car but two commuters with a driver’s license), the EMU of commuting mode choices of the individual commuters influences the allocation of the car as well as the *household commuting distance* and *angle*.

- For no-car households, the EMU of two commuters influences the *household commuting distance* and *angle*.

- For car-sufficient households, the EMU of two commuters influences the *household commuting distance* and *angle*. 

The EMU of mode choices or car allocation choices provides a utility-based accessibility measure for *household commuting distance* and *angle*, which is the most theoretically sound and disaggregate accessibility measure (Silva, 2013). Since the *household commuting distance* and *angle* are continuous variables, we use the Cobb-Douglas direct utility formulation for modelling the two attributes of the HWSC. Using the Cobb-Douglas direct utility function, the following formulations are assumed (Varian, 1992):

\[
D = e^{\theta' (EM_{commute1} + EM_{commute2}) + \sum \theta z} e^\tau = e^{D_{par}} e^\tau \\
A = e^{\alpha' (EM_{commute1} + EM_{commute2}) + \sum \alpha w} e^\psi = e^{A_{par}} e^\psi
\]

Here, D refers to *household commuting distance* and A refers to *angle*; \(D_{par}\) and \(A_{par}\) indicate parameterized functions of D and A, where \(EM_{commute1}\) and \(EM_{commute2}\) refer to the EMUs of mode choices of the two commuters; \(\theta'\) and \(\alpha'\) are coefficients of EMU functions; z refers to a set of variables influencing *household commuting distance* and \(\theta\) refers to their corresponding coefficients; w refers to a set of variables influencing the *angle* and \(\alpha\) refers to their corresponding coefficients. The random utility components of *household commuting distance* and *angle* are specified by exponential functions of \(\tau\) and \(\psi\) respectively.

For the econometric formulations in the proposed joint modelling structure, we need to assume the distribution types of the random components of the random utility functions defined by equations 1 to 5. We assume that:

- The random error components of the mode choice utility functions (\(\epsilon_{commute1}\) and \(\epsilon_{commute2}\)) follow an independent and identically distributed (IID) type I extreme value distribution with scale parameters (\(\mu_{commume1}\) and \(\mu_{commute2}\)).
- The random error component of the household car allocation choice utility function (\(\epsilon_{allocate}\)) follows an independent and identically distributed (IID) type I extreme value distribution with scale parameters (\(\mu_{allocate}\)).
- The random error components (\(\tau\) and \(\psi\)) of *household commuting distance* and *angle* follow a joint bivariate normal distribution with variances (\(\sigma_D^2\) for *household commuting distance* and \(\sigma_A^2\) for *angle*) and the correlation between D and A is \(\rho\).
Under the IID random utility assumptions, the choices of the commuting mode of two commuters are (Ben-Akiva and Lerman 1985):

$$P(\text{commute}_1) | Ch1 = \frac{\exp(\mu_{\text{commute}_1} V_{\text{commute}_1})}{\sum_{M1 \in Ch1} \exp(\mu_{\text{commute}_1} V_{M1})}$$

(6)

$$P(\text{commute}_2) | Ch2 = \frac{\exp(\mu_{\text{commute}_2} V_{\text{commute}_2})}{\sum_{M \in \text{Ch2}} \exp(\mu_{\text{commute}_2} V_{M})}$$

(7)

Here, Ch1 and Ch2 are the choice sets of commuting modes for the two commuters. Such choice sets are assumed to be systematically identifiable. In the case of car-sufficient and no-car households, both choice sets are assumed to be independent and defined only by feasibilities of modal options depending on home and work destination zones. However, for households with one car but two commuters with driver’s licenses, the auto-drive mode options in the choice set one and two are mutually exclusive, which is assumed to be defined by the car allocation model. There are some observations of car-deficient households where none of the commuters are observed to be choosing the auto driving mode. Unlike commuting mode choice, car allocation choice is considered to be a household-level choice and a function of different household-level variables along with the EMUs of commuting mode choices of the two commuters. Under the IID type, I extreme value assumption of individual commuting mode choice random utility components (Ben-Akiva and Lerman 1985), the EMUs (EM_{\text{commute}_1} and EM_{\text{commute}_2}) of commuting mode choices are:

$$EM_{\text{commute}_1} = \ln\left( \sum_{M1 \in \text{Ch1}} \exp(\mu_{\text{commute}_1} V_{M1}) \right)$$

(8)

$$EM_{\text{commute}_2} = \ln\left( \sum_{M2 \in \text{Ch2}} \exp(\mu_{\text{commute}_2} V_{M2}) \right)$$

(9)

Considering IID type I extreme value distribution for the random utility component, the car allocation choice among households with one car but two commuters with driver’s licenses is:
Here, \(P(\text{allocate}_1)\) and \(P(\text{allocate}_2)\) refer to the probabilities of allocating the car (making the auto driving option feasible) to commuter 1 and commuter 2.

Under a bivariate normal density assumption for the random direct utilities of household commuting distance and angle (\(\tau\) and \(\psi\) in equation 4 and 5), the joint probability of a household commuting distance and angle pair \((DA)\), \(P(DA)\) is (Hamedani and Tata, 1975):

\[
P(DA) = \frac{1}{2\pi\sigma_D\sigma_A\sqrt{1 - \rho^2}} \exp\left(-\frac{1}{2(1 - \rho^2)} \left[\frac{(\ln(D) - D_{\text{par}})^2}{\sigma_D^2} + \frac{(\ln(A) - A_{\text{par}})^2}{\sigma_A^2} - \frac{2\rho(\ln(D) - D_{\text{par}})(\ln(A) - A_{\text{par}})}{\sigma_D\sigma_A}\right]\right)
\]  

(12)

The joint likelihood of two-worker households’ commuting mode choices for both commuters, the car allocation choice, household commuting distance and angle is:

\[
L = (P(\text{commute}_1) | Ch1) \times (P(\text{commute}_2) | Ch2) \\
\times P(\text{allocate}_1) \times P(\text{allocate}_2) \times P(DA)
\]

(13)

For no-car or car-sufficient households, car allocation choice is not part of the model and hence the joint likelihood \(L\) becomes:

\[
L = (P(\text{commute}_1) | Ch1) \times (P(\text{commute}_2) | Ch2) \times P(DA)
\]

(14)
This likelihood function corresponds to the joint econometric model and has a closed form. Therefore, it is estimated using the classical maximum likelihood estimation technique. The joint likelihood functions are programmed in GAUSS (Aptech Systems 2013) and the parameters are estimated by using a gradient search algorithm called the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm. This algorithm is an iterative method used in numerical optimization for solving unconstrained nonlinear optimization problems.

The IID assumption on the random error component of mode choice random utility functions is restrictive in capturing full substitution patterns of alternative modes. Therefore, an error component modelling approach for commuting mode choices is also considered (Train, 2009). The error component modelling approach considers the random utility components to be further divided into an IID random component and a full variance-covariance random component.

Equations 2 and 3 are rewritten as follows:

\[
\epsilon_{\text{commute}1} = \epsilon_{\text{commute}1}^{\prime} + \epsilon_{\text{commute}1}^{\prime\prime} \tag{15}
\]

\[
\epsilon_{\text{commute}2} = \epsilon_{\text{commute}2}^{\prime} + \epsilon_{\text{commute}2}^{\prime\prime} \tag{16}
\]

Here, \(\epsilon_{\text{commute}1}^{\prime}\) and \(\epsilon_{\text{commute}2}^{\prime}\) follow the IID type I extreme value distribution, but \(\epsilon_{\text{commute}1}^{\prime\prime}\) and \(\epsilon_{\text{commute}2}^{\prime\prime}\) have multivariate normal distributions.

A wide variety of substitution patterns can be tested with this specification. Cholesky factorization (upper triangular matrix of the full variance-covariance matrix) is used to further specify the variance-covariance of multivariate random components inside the choice model formulation as (Train, 2009):

\[
P(\text{commute}_1 \mid Ch1) = \int \frac{\exp(\mu_{\text{commute}1}(V_{\text{commute}1} + \epsilon_{\text{commute}1}^{\prime\prime}))}{\sum_{M \in Ch1} \exp(\mu_{\text{commute}1}(V_{M1} + \epsilon_{M1}^{\prime\prime}))} f(\epsilon_{\text{commute}1}^{\prime\prime}) d\epsilon_{\text{commute}1}^{\prime\prime} \tag{17}
\]

\[
P(\text{commute}_2 \mid Ch2) = \int \frac{\exp(\mu_{\text{commute}2}(V_{\text{commute}2} + \epsilon_{\text{commute}2}^{\prime\prime}))}{\sum_{M \notin Ch2} \exp(\mu_{\text{commute}2}(V_{M2} + \epsilon_{M2}^{\prime\prime}))} f(\epsilon_{\text{commute}2}^{\prime\prime}) d\epsilon_{\text{commute}2}^{\prime\prime} \tag{18}
\]
The resulting likelihood functions have a non-closed form and cannot be estimated using the classical maximum likelihood estimation technique. Maximum simulated likelihood (MSL) is widely used for estimation of such models (Train, 2009). In this research, the likelihood functions are programmed in GUASS (Aptech Systems 2013) using the MSL estimation technique. For simulation, the scrambled Halton sequence (SHS) is used, which is proven to be the most efficient method that requires a low number of simulation replications (Bhat, 2003). It is found that with SHS, the parameter estimates stabilize within a very small number (less than 50) of simulation replications. However, 100 replications are used for the final specification.

4.5 Empirical Investigation

The summary of empirical models is presented in Table 4.2. Two types of models are estimated: the first considers IID assumptions for the mode choice random utility component, and the second considers the error component model for mode choices. The former is identified as a non-mixed model, as the mode choice model random utility components are assumed to be non-mixed (same variance for all modes’ random utility function).

The mixed model estimates separate variances for different modes’ random utility functions and accommodates random heteroskedasticity as well as random preference heterogeneity through mixing multivariate normal distribution with IID type I extreme value distribution. The non-mixed model accommodates only the systematic heteroskedasticity through scale parameterization. The mixed model and non-mixed models are presented for comparison purposes. Both models have similar results in terms of expected signs; however, the magnitudes of parameters are moderately different. Since the results are similar, the ensuing discussion generally does not distinguish between the mixed and non-mixed models unless otherwise noted.
Table 4.2: Summary of empirical model estimations

<table>
<thead>
<tr>
<th></th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations</td>
<td>3223</td>
<td>3223</td>
</tr>
<tr>
<td>Loglikelihood of full model</td>
<td>-15093</td>
<td>-15238</td>
</tr>
<tr>
<td>Loglikelihood of constant-only model</td>
<td>-25782</td>
<td>-18133</td>
</tr>
<tr>
<td>Loglikelihood of null model</td>
<td>-55086</td>
<td>-46143</td>
</tr>
<tr>
<td>Rho-Square value against null Model</td>
<td>0.73</td>
<td>0.67</td>
</tr>
<tr>
<td>Rho-Square value against constant-only model</td>
<td>0.41</td>
<td>0.16</td>
</tr>
</tbody>
</table>

4.5.1 Selection of Independent Variables

The selection of independent variables is based on theory and *a-priori* hypotheses regarding factors that affect mode choices. The mode choice model consists of individual specific variables and level-of-service attributes of the various travel modes. The individual specific variables gender and age are estimated with alternative specific coefficients, which reflect different preferences for various travel modes arising from the influence of these two variables. The variable age is used as a continuous variable rather than as age classifications because not all age classifications are well represented in the dataset. Of all the transportation level-of-service variables, only *in-vehicle travel time* and *cost* are estimated with generic coefficients. This represents an assumption that a unit of time and cost has the same marginal effect on utility regardless of the travel mode (Ben-Akiva and Lerman, 1985). The variables *in-vehicle travel time*, *cost*, *age*, and *gender* are all important considerations in mode choice studies and have been used in models as early as the study by Lisco (1967).

Variables used in the Cobb-Douglas direct utility models for *household commuting distance* and *angle* include *total congestion delays*, *household annual income*, *average age* and other variables related to land-use. The variable *total congestion delays* is used to capture the effects of congestion levels on the HWSC. The variable *household annual income* is not specified for the non-mixed model as it is found to be statistically insignificant. *Average age* is also an important variable to consider as existing studies indicate that varying age groups, especially the pre-elderly, can have markedly different preferences for home locations (Morrow-Jones & Kim, 2009). The data used for the modelling does not provide detailed information regarding the land use attributes of the urban area. Instead, the following variables are used as proxies to capture the
influence of land-use: 1) home zone population density; 2) total transit distance by auto distance from home to work; and 3) total transit distance by auto distance from home to CBD. The latter two variables are also measures of accessibility that are based on the performance of the transit system, which are important factors according to Zongad and Pieters (2005). Finally, the expected maximum utilities of mode choices, also referred to throughout this research as commuting modal accessibility, is an explanatory variable used to draw a relationship with household commuting distance and angle. Silva (2013) notes that the expected maximum utility of mode choices (or modal accessibility) provides a theoretically sound accessibility measure.

4.5.2 Estimation of Empirical Models

The final specifications all models are selected by considering expected signs and t-statistics of the parameters. We use a 95 percent confidence limit for one-tailed tests (critical t-statistics value of 1.64) while investigating the statistical significance of the parameters. One-tailed tests are performed since we have a theoretical understanding and, in some cases, strong intuition regarding the effects of the variables (whether positive or negative) on the models. A small number of parameters with t-statistics lower than 1.64 are retained in the model given their importance in explaining behaviour and due to the fact that they have the expected signs. For parsimony, the variances of household commuting distance and angle are normalized to unity, however, the correlation coefficient (ρ) is parameterized as a function of variables (q) and corresponding coefficients (η). In order to maintain the limits of (-1≤ ρ ≤+1), the following functional form of parameterization is used:

\[ \rho = \frac{1 - \exp(q\eta)}{1 + \exp(q\eta)} \] (19)

The variances are normalized to ensure a reasonably low magnitude of parameters. For the mode choice component of the joint econometric model, a generic model is used for both commuters within the household. This does not imply that both commuters have exactly the same mode choice models, since the choice sets may vary for each commuter. Also, different commuters may have different level-of-service attributes corresponding to their workplace locations. Furthermore, systematically defined choice sets for mode choices of each commuter are used. A
generic mode choice model is parsimonious in this case as the commuters within a household are not labelled.

The goodness-of-fit of the estimated models is assessed by using the rho-square value, which is calculated by comparing the final loglikelihood values against the null and constants-only models. The null model considers: 1) all modes are equally attractive for the mode choice component; 2) null functions for household commuting distance and angle; and 3) zero correlation between household commuting distance and angle. The constants-only model considers: 1) only alternative-specific constants for the mode choice component; 2) only constants for the household commuting distance and angle functions; and 3) zero correlation between household commuting distance and angle. The rho-square values are calculated as the difference between one and the ratio of the full model loglikelihood value to the null or constants-only model loglikelihood value. A higher rho-square value indicates a better fit of the joint econometric model to the observed data. The mixed model indicates a higher goodness-of-fit than the non-mixed model. This demonstrates that there is considerable random heteroskedasticity in the commuting mode choices of two-worker households. It follows that the sources of randomness for choosing different commuting modes are not the same across all modes.

4.5.3 Results of the Mode Choice Model

The mixed model considers the correlation between random utilities of alternative modes of commuting. The Cholesky factor of the empirical model (which is the lower triangular matrix L, such that L^TL = the variance-covariance matrix) provides insight into the correlations between the various mode choice alternatives. According to the results, all diagonal elements (S11, S22, S33, S44, S55, S66 and S77) and only two off-diagonal elements (S65 and S76) of the Cholesky factor are found to be statistically significant (refer to Table 4.2). The estimated off-diagonal element for kiss-and-ride and bike modes (S65) reveals a substitutive relationship. This indicates that commuters who choose kiss-and-ride are also likely to choose the bike mode more than any other mode. Although these modes appear to be quite different in terms of attributes, commuters who choose them may not have a personal automobile available. Commuters who choose kiss-and-ride may do so since walking to the transit station (the transit-walk access mode) may not be a viable option due to physical distance. Accordingly, if kiss-and-ride is not available, the bike
mode may be the only viable option. The off-diagonal element for walk and bike modes (S76) also reveals a substitutive relationship. This is intuitive as both are active transportation modes and may be substituted since they share similar attributes. The estimated diagonal elements of the Cholesky factor capture the heteroskedasticity in the random choices of commuters. The diagonal elements of the Cholesky factor are indicative of the number of sources of randomness relative to the auto driving mode. The park-and-ride mode has the greatest number of sources of randomness followed by walk, transit with walk access and bike. The results reveal that commuters in two-worker households have significant random heteroskedasticity in commuting mode choices. Capturing this heteroskedasticity has increased the goodness-of-fit of the mixed model and is more effective in describing mode choice behaviour of these households.

Table 4.3: Cholesky factors in mode choice component of heteroskedastic model

<table>
<thead>
<tr>
<th>Mixed Model</th>
<th>Parameter</th>
<th>t-Stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Auto driving</td>
<td>S11</td>
<td>1.00</td>
</tr>
<tr>
<td>2: Auto passenger</td>
<td>S33</td>
<td>1.45</td>
</tr>
<tr>
<td>3: Transit-walk access</td>
<td>S44</td>
<td>2.27</td>
</tr>
<tr>
<td>4: Park &amp; ride</td>
<td>S55</td>
<td>-2.67</td>
</tr>
<tr>
<td>5: Kiss &amp; ride</td>
<td>S65</td>
<td>-1.70</td>
</tr>
<tr>
<td>6: Bike</td>
<td>S66</td>
<td>-2.12</td>
</tr>
<tr>
<td>7: Walk</td>
<td>S76</td>
<td>-1.55</td>
</tr>
<tr>
<td></td>
<td>S77</td>
<td>2.32</td>
</tr>
</tbody>
</table>

The results of the mode choice model indicate that the alternative specific constants (ASC) corresponding to the various travel modes are moderate (refer to Table 4.4). This suggests that the model specification has an adequate number of variables that explain systematic utilities of the commuting modes. In-vehicle travel time and cost have expected negative signs in both the mixed and non-mixed models. Total distance is considered for the bike and walk modes since they are more sensitive to distance than other modes. Access walk time and waiting time are considered for all transit modes and have expected negative signs. Amongst the individual specific attributes, only age and gender are found to be significant in both models. The results indicate that females do not prefer the bike mode relative to their male counterparts. Conversely, females prefer the auto passenger and kiss-and-ride modes. Also, female commuters prefer the
park-and-ride mode over the transit with walk access mode, while the walk mode is less
preferable than transit modes. The variable *age* influences mode choice. Older commuters prefer
auto driving over the modes kiss-and-ride, auto passenger and transit-walk access. However,
non-motorized modes are more preferred by older commuters than younger commuters.
Table 4.4: Systematic utility function of mode choice model

<table>
<thead>
<tr>
<th></th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>t-Stat</td>
</tr>
<tr>
<td>Alternative specific constant (asc)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: Auto driving</td>
<td>-2.06</td>
<td>-5.85</td>
</tr>
<tr>
<td>2: Auto passenger</td>
<td>0.00</td>
<td>---</td>
</tr>
<tr>
<td>3: Transit-walk access</td>
<td>3.38</td>
<td>12.43</td>
</tr>
<tr>
<td>4: Park &amp; ride</td>
<td>-4.72</td>
<td>-4.43</td>
</tr>
<tr>
<td>5: Kiss &amp; ride</td>
<td>-4.39</td>
<td>-2.12</td>
</tr>
<tr>
<td>6: Bike</td>
<td>-5.43</td>
<td>-4.17</td>
</tr>
<tr>
<td>7: Walk</td>
<td>2.58</td>
<td>5.26</td>
</tr>
<tr>
<td>In-vehicle travel time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generic across all modes</td>
<td>-0.05</td>
<td>-16.92</td>
</tr>
<tr>
<td>Cost (2011 Canadian dollars)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generic across all modes</td>
<td>-0.02</td>
<td>-2.88</td>
</tr>
<tr>
<td>Total distance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6: Bike</td>
<td>-0.43</td>
<td>-10.64</td>
</tr>
<tr>
<td>7: Walk</td>
<td>-1.75</td>
<td>-20.15</td>
</tr>
<tr>
<td>Access walk time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit walk access, Park &amp; ride, Kiss &amp; ride</td>
<td>-0.01</td>
<td>-4.16</td>
</tr>
<tr>
<td>Waiting time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit walk access, Park &amp; ride, Kiss &amp; ride</td>
<td>-0.02</td>
<td>-1.77</td>
</tr>
<tr>
<td>Gender: Female</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: Auto driving</td>
<td>0.00</td>
<td>---</td>
</tr>
<tr>
<td>2: Auto passenger</td>
<td>0.83</td>
<td>8.55</td>
</tr>
<tr>
<td>3: Transit-walk access</td>
<td>0.44</td>
<td>5.63</td>
</tr>
<tr>
<td>4: Park &amp; ride</td>
<td>0.62</td>
<td>2.73</td>
</tr>
<tr>
<td>5: Kiss &amp; ride</td>
<td>0.82</td>
<td>2.55</td>
</tr>
<tr>
<td>6: Bike</td>
<td>-0.77</td>
<td>-4.00</td>
</tr>
<tr>
<td>7: Walk</td>
<td>0.18</td>
<td>1.04</td>
</tr>
</tbody>
</table>
Logarithm of age

<table>
<thead>
<tr>
<th></th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>t-Stat</td>
</tr>
<tr>
<td>1: Auto driving</td>
<td>0.00</td>
<td>---</td>
</tr>
<tr>
<td>2: Auto passenger</td>
<td>-1.31</td>
<td>-12.43</td>
</tr>
<tr>
<td>3: Transit-walk access</td>
<td>-1.26</td>
<td>-13.43</td>
</tr>
<tr>
<td>4: Park &amp; ride</td>
<td>-0.72</td>
<td>-2.60</td>
</tr>
<tr>
<td>5: Kiss &amp; ride</td>
<td>-1.53</td>
<td>-2.63</td>
</tr>
<tr>
<td>6: Bike</td>
<td>0.71</td>
<td>3.04</td>
</tr>
<tr>
<td>7: walk</td>
<td>0.49</td>
<td>3.16</td>
</tr>
</tbody>
</table>

Table 4.5: Exponential function of root scale parameter for car allocation in one car household

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of car per household members</td>
<td>---</td>
<td>0.21 4.50</td>
</tr>
<tr>
<td>Logarithm of the ratio of total transit distance from home to two workplaces by auto distance from home to two workplaces</td>
<td>---</td>
<td>0.19 2.78</td>
</tr>
<tr>
<td>Household annual income: $0-$29999</td>
<td>---</td>
<td>0.22 3.20</td>
</tr>
<tr>
<td>Household annual income: $30000-$59999</td>
<td>---</td>
<td>0.06 1.46</td>
</tr>
</tbody>
</table>

Table 4.6: Additional exponential function to root scale parameter function for mode choice

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household size</td>
<td>---</td>
<td>-6.00 -0.40</td>
</tr>
</tbody>
</table>

4.5.4 Results of the Scale Parameters

The car allocation model is considered for car-deficient households who have one car and two commuters with a driver’s license. For these households, a two-level nested logit modelling framework is proposed whereby the mode choice model (lower level choice) is nested within the
car allocation choice model (upper-level choice). To ensure the validity of the proposed econometric formulation, the scale parameter of both choice models must be positive and the scale parameter of the mode choice model (lower level choice) must be greater than that of the car allocation choice model (higher level choice). The scale parameter of the car allocation choice model is referred to the root scale parameter. In order for the proposed nesting structure to hold true, the scale parameter of the mode choice model is assumed to be the summation of the root scale parameter and an additional exponential function, which is parameterized to capture the heteroskedasticity across two-worker households. This function is expressed in exponential form to ensure positivity. The confirmation of the scale parameters of higher and lower level choices must be checked to maintain the scale hierarchy of a joint model (Sasic and Habib, 2013). However, in the case of car-sufficient or no-car households, a car allocation model is not necessary, but the mode choice scale parameter remains the summation of the root scale parameter and the additional exponential function. The scale parameter explains the randomness of the corresponding choice process. A higher scale parameter value indicates a lower randomness of the choice process and vice versa. Moreover, the inverse of the scale parameter becomes the coefficient of the EMU of mode and car allocation choices in the direct utility functions of models for household commuting distance and angle.

The mixed model could not accommodate any significant variables for the scale parameters. Perhaps the accommodation of the mode choice random heteroskedasticity and preference heterogeneity in the mixed model does not leave any systematic scale variation. However, the non-mixed model accommodates systematic heteroskedasticity through the scale parameter functions. For the scale parameter functions, only household-specific variables are considered (refer to Table 4.5). No significant variables are identified in the additional component of the scale parameter. In Table 4.5, one variable with an insignificant coefficient is reported for comparison. Moreover, the value of the additional scale parameter to the root scale parameter is close to zero (exponential of six multiplied by household size). This means that both the car allocation and mode choice models have the same scale parameter. It can be deduced that for car-deficient households, car allocation and mode choices are simultaneous rather than hierarchical decisions.
Of the four variables used to explain the scale parameters, the lower household annual income has the highest impact (i.e. annual income between $0-$29,999). This suggests that lower-income households have more stable (less random) commuting mode and car allocation choices. Medium-income households (annual income between $30,000-$59,999) have more stable choices than higher-income households but less stable choices than lower-income households. Higher auto ownership indicates stable mode choices. Transit accessibility, namely the variable ratio of total transit distance from home to two work places by auto distance from home to two work places, is considered in explaining the scale parameter. This result indicates that higher transit accessibility influences stable car allocation and commuting mode choices.

4.5.5 Results of Car Allocation Model

The car allocation choice model has three variables in addition to the EMU of mode choices (refer to Table 4.7). Among these variables, job status: full time has the highest coefficient value. This suggests that commuters in car-deficient households who have full-time jobs acquire a higher utility from using cars. The variable gender: male has a positive coefficient value which indicates that their use of the car is prioritized. The positive coefficient for the variable ratio of transit distance by auto distance indicates that commuters with a longer transit commute distance relative to the auto commute distance, also get a higher priority for car usage.

<table>
<thead>
<tr>
<th></th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>t-Stat</td>
</tr>
<tr>
<td>Ratio of transit distance by auto distance</td>
<td>0.89</td>
<td>17.56</td>
</tr>
<tr>
<td>Job status: Full time</td>
<td>2.52</td>
<td>14.98</td>
</tr>
<tr>
<td>Gender: male</td>
<td>0.51</td>
<td>3.46</td>
</tr>
<tr>
<td>Expected maximum utility of mode choice model</td>
<td>1.00</td>
<td>---</td>
</tr>
</tbody>
</table>

4.5.6 Results of the Angle Model

The direct utility model for angle considers several variables. The results indicate that angle is significantly affected by the EMU of the commuting mode choices for both workers. The
positive coefficient of the variable *sum of expected maximum utilities of mode choices* indicates that a higher commuting modal accessibility leads to a wider *angle*. A wider *angle* is associated with home locations that are closer to the line connecting and in between the two workplaces. Any location on this line results in the widest possible *angle* of 180 degrees. The variable *household annual income* has a significant impact on this *angle*. Household annual incomes between $30,000-$59,999 have a positive influence on widening the *angle*. Household annual incomes between $60,000-$89,999 have a negative influence thereby narrowing the *angle*.

Transit accessibility from home to the CBD has a significant influence on *angle*. The results indicate that the variable *ratio of total transit distance from home to CBD by auto distance from home to CBD* has a negative coefficient value, suggesting that longer distances from home to the CBD have a positive association with narrower *angles*. Also, the results indicate that the variable *ratio of total transit distance from home to two workplaces by auto distance from home to two workplaces* has a negative coefficient value, suggesting a positive association with *angle*.

Similarly, the location of two workplaces relative to the CBD, measured by the variable *angle between two workplaces at the CBD*, has a significant association with *angle*. This finding suggests that a wider angle between two workplaces at the CBD is associated with a wider *angle*. The variable *total congestion delays*, measured as the difference between actual auto travel times and free-flow auto travel time, has a positive coefficient value which indicates that higher congestion delays are associated with a wider *angle*.

*Home zone population density* is a significant variable with a positive coefficient value. This suggests that densely populated zones are positively associated with *angle*. A higher average age of both commuters is also positively associated with a wider *angle*. This indicates that older workers tend to choose more optimal home locations with respect to commuting distance (i.e. closer to a line connecting and in between two workplaces).
Table 4.8: Results of angle model (workplace 1-home-workplace two angles)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>t-Stat</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.38</td>
<td>-2.21</td>
</tr>
<tr>
<td>Logarithm of total congestion delays (minutes)</td>
<td>0.08</td>
<td>7.46</td>
</tr>
<tr>
<td>Angle of two workplaces with CBD divided by 180</td>
<td>2.10</td>
<td>32.20</td>
</tr>
<tr>
<td>Logarithm of the ratio of total transit distance from home to two workplaces by auto distance from home to two workplaces</td>
<td>2.52</td>
<td>24.17</td>
</tr>
<tr>
<td>Logarithm of average age of two workers</td>
<td>0.42</td>
<td>11.79</td>
</tr>
<tr>
<td>Logarithm of home zone population density in 10000</td>
<td>0.01</td>
<td>1.50</td>
</tr>
<tr>
<td>Logarithm of the ratio of total transit distance from home to CBD by auto distance from home to CBD</td>
<td>-0.54</td>
<td>-3.93</td>
</tr>
<tr>
<td>Household annual income: $60000-$89999</td>
<td>-0.15</td>
<td>-3.27</td>
</tr>
<tr>
<td>Household annual income: $30000-$59999</td>
<td>0.04</td>
<td>1.23</td>
</tr>
<tr>
<td>Sum of expected maximum utilities of mode choices</td>
<td>0.18</td>
<td>19.76</td>
</tr>
</tbody>
</table>

4.5.7 Results of the Household Commuting Distance Model

The direct utility model for household commuting distance considers several variables. The results indicate that household commuting distance is inversely affected by the expected maximum utilities of the commuting mode choices. This suggests that a higher commuting modal accessibility leads to a reduction in total commuting distances of two-commuter households. This is likely since households residing in areas that yield higher accessibility do not need to be located far away from their workplaces. Unlike the direct utility function of angle, we did not find household income categories to be significant variables in the model. Transit accessibility from home to the CBD has an influence on household commuting distance. The results indicate that the variable the ratio of total transit distance from home to CBD by auto distance from home to CBD has an inverse relationship with household commuting. This suggests that a longer transit distance from home to the CBD relative to the auto mode is
associated with shorter household commuting distances. Similarly, transit accessibility from home to two workplaces also has an influence on *household commuting distance*. The results indicate that the variable *ratio of total transit distance from home to two workplaces by auto distance from home to two workplaces* has a positive association with *household commuting distance*. This suggests that a longer distance of transit route from home to two workplaces relative to the auto mode is associated with longer household commuting distances. The relative location of two workplaces from the CBD measured by the angle between two workplaces at the CBD has a significant influence on *household commuting distance*. The results indicate that a wider angle between two workplaces at the CBD is associated with longer commuting distances. We also consider congestion delays measured as the difference between the actual auto travel time to free-flow auto travel time as a variable in the model. The findings suggest that a higher congestion delay is associated with longer total commuting distances. Home zone population density is a significant variable and it is evident that a denser home zone is associated with shorter total commuting distances. A higher average age of two commuters is associated with longer total commuting distances.
Table 4.9: Results of the household commuting distance model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2.04</td>
<td>1.66</td>
</tr>
<tr>
<td>Logarithm of total congestion delays (minutes)</td>
<td>0.26</td>
<td>0.16</td>
</tr>
<tr>
<td>Angle of two workplaces with CBD divided by 180</td>
<td>---</td>
<td>0.13</td>
</tr>
<tr>
<td>Logarithm of the ratio of total transit distance from home to two workplaces by auto distance from home to two workplaces</td>
<td>---</td>
<td>0.18</td>
</tr>
<tr>
<td>Logarithm of average age of two workers</td>
<td>---</td>
<td>0.08</td>
</tr>
<tr>
<td>Logarithm of home zone population density in 10000</td>
<td>-0.10</td>
<td>-0.07</td>
</tr>
<tr>
<td>Logarithm of the ratio of total transit distance from home to CBD by auto distance from home to CBD</td>
<td>-0.44</td>
<td>-0.44</td>
</tr>
<tr>
<td>Household annual income: $60000-$89999</td>
<td>-0.16</td>
<td>0.00</td>
</tr>
<tr>
<td>Sum of expected maximum utilities of mode choices</td>
<td>-0.16</td>
<td>-0.37</td>
</tr>
</tbody>
</table>

4.5.8 Correlation between Angle and Total Commuting Distance

Spatial variables are used to parameterize the correlation coefficient between unobserved factors affecting the utilities of angle and household commuting distance. The results indicate that larger angles between two workplaces at the CBD increase the inverse correlation between angle and household commuting distance. However, a higher annual income reduces the correlation between angle and household commuting distance. The driving distance from home to the CBD interacts with the apartment/condo dwelling type. The results suggest that with increasing distances from the CBD, the inverse (or negative) correlation between total commuting distance and angle reduces (refer to Table 4.10).

Results of this study show that total commuting distances become less responsive to changes in the position of the home location as the home location moves away from the CBD. This finding is consistent with the geometry of a triangle. Suppose two fixed points on a triangle represent the work locations. Moving the third point, which represents the home location, away from the line
connecting the two fixed points would result in a reduced correlation between angle and household commuting distance. Reduced correlation between these variables is a property of the third point’s distance. Accordingly, if the third point (home location) is located closer to the two fixed points (work locations), the correlation would be higher. Since the findings of this research confirm the above-described correlation, it is an indication that households located far from the CBD also work primarily in the CBD or in job centres situated away from residential areas, and therefore have longer commuting distances.

Table 4.10: Correlation between angle and household commuting distance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mixed Model</th>
<th>Non-Mixed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>Parameter</td>
</tr>
<tr>
<td></td>
<td>t-Stat</td>
<td>t-Stat</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.26</td>
<td>-0.18</td>
</tr>
<tr>
<td></td>
<td>-2.17</td>
<td>-3.59</td>
</tr>
<tr>
<td>Driving distance from home to CBD' x 'Dwelling type: Apartment/Condos'</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td></td>
<td>-0.96</td>
<td>-1.01</td>
</tr>
<tr>
<td>Household annual income greater than $119999</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>0.31</td>
<td>1.17</td>
</tr>
<tr>
<td>Angle between two work places at CBD normalized by 180</td>
<td>-0.20</td>
<td>-0.20</td>
</tr>
<tr>
<td></td>
<td>-0.54</td>
<td>-1.28</td>
</tr>
</tbody>
</table>

4.6 Policy Implications

In this research, commuting modal accessibility is considered an attribute of the transportation system performance in the NCR. It can accordingly be deduced that the transportation system has a significant impact on the land-use configuration of two-worker households (i.e. the HWSC). The empirical model reveals that increasing commuting mode choice accessibility yields a wider angle and shorter household commuting distance. Although household commuting distance and angle are inversely correlated, it appears that commuting modal accessibility has a moderately higher impact on angle than on household commuting distance. The research reveals that modal accessibility has parameter values of 0.18 and -0.16 for angle and household commuting distance respectively.

Policies suggested as a result of this research are aimed at improving the ability of two-worker households to optimize their home location thereby yielding shorter daily commute trips. This would consequently alleviate strains on the transportation system by reducing commuting
distances and road congestion. For this research, high modal accessibility implies that there are multiple transportation options or mode choices for work trips. Home locations without direct access to public transportation or where the only viable transportation option is the automobile could be considered to have a lower level of modal accessibility than a home location that is within close proximity to a bus route or subway stop. Results of this research indicate high modal accessibility is associated with shorter commuting distances. Generally, access to automobile travel is largely a function of household income or the financial ability to own and operate an automobile. Therefore, the policy implications referred to herein do not deal with increasing modal accessibility through improving transportation via the automobile. Instead, the results of this study are used to suggest improving access to public transit, which can be influenced by transportation policies. Transportation policies should be aimed at providing public transit service where it currently does not exist. Expanding public transit coverage may be beneficial to the optimization of home locations in addition to improving the frequency of service on existing transit lines as it would increase the modal accessibility of a greater number of households.

4.7 Chapter Summary

This chapter examined the impact of commuting modal accessibility on the HWSC of two-worker households using a joint econometric modelling structure. The results indicated that higher commuting modal accessibility is significantly associated with a reduction in *household commuting distance* and a widening of *angle*. Both of these effects lead to a more optimal spatial arrangement, strictly from the perspective of minimizing commuting distances. An important policy implication arising from these modelling results was discussed, namely a transportation policy to improve the quality and coverage of public transit service to areas not well served by transit.

This chapter specifically examined the influence of a transportation system attribute (commuting modal accessibility) on a land-use system attribute (HWSC of two-worker households). It explored the factors that contribute to an optimal HWSC (i.e. home locations closer to a line connecting and in between the two workplaces). However, it did not specifically examine whether households would adjust their HWSC to be closer or farther away from one commuter’s
workplace than the other. In other words, do commuters in two-worker households make trade-offs? This is also an important issue to study as the presence of two-worker households is viewed by some as a hindrance to achieving jobs-housing balance. However, if two-worker households are found to make commuting trade-offs, then some level of jobs-housing balance may be achievable. As such the next chapter examines this specific question about commuting trade-offs in two-worker households.
CHAPTER 5

5 Relationship between Home-Work Spatial Configuration and Commuting Trade-offs of Two-worker Households

5.1 Chapter Overview

The second step of phase one of this research is presented in this chapter. Phase one focusses on the context of two-worker households. The second step investigates commuting trade-offs of two-worker households by analyzing the adjustments these households make to their HWSCs. For the purposes of this research, a commuting trade-off occurs when a home relocation results in one worker incurring a higher proportion of the household commuting distance in order for the other worker to work closer to the common home location, thereby reducing their partner’s commute distance. Econometric models are developed for household commuting distance, which as indicated in Chapter four, is an attribute of the HWSC. This research uses stated preference data collected in 2014 from households with home and work locations in the Greater Toronto Area (GTA). This chapter is organized into the following sections: Section 5.2 briefly introduces the motivation and research design for this study. Section 5.3 provides an overview of the study area and data used for modelling. Section 5.4 outlines the econometric modelling framework, and Section 5.5 presents the modelling results. Section 5.6 discusses the policy implications arising from the results. A summary of the chapter is presented in Section 5.7.

5.2 Introduction

5.2.1 Motivation

Where people live and work and how they travel between those destinations are among the most important considerations of land-use and transportation planning. It is therefore important to understand the behaviours of individuals and households whose decisions ultimately shape the urban form. One such important behaviour is the commuting trade-off made between partners within a two-worker household in respect of their individual commute distances.
This research investigates households of two out-of-home workers with home and work locations in the GTA. Two-worker households are an important group to study because, in the City of Toronto alone, two-worker households make up to 28 percent of the population (Habib, 2014). Also, households, where both workers travel outside of the home to two separate work locations, are an interesting household type to examine as they face the dual constraint of considering two work locations when making commuting choices. That dual constraint can lead to commuting trade-offs between individuals in the household. Our research examines those commuting trade-offs using stated preference data and multi-level modelling.

5.2.2 Research Design

As set out in Chapter four, the HWSC of two-worker households is defined by household commuting distance and angle. In this step of the research, econometric models are developed for household commuting distance. The models employ several explanatory variables, including angle, which is introduced in Chapter four, and an additional variable, the difference between longest and shortest Euclidean home to work distances.

The variable difference between longest and shortest Euclidean home to work distances is used to provide insights into commuting trade-offs. If the difference between individual commutes increases by a certain amount, and household commuting distance increases by the same amount or greater, then it can be concluded that the individual commute distances are compliments (meaning that partners do not make trade-offs). If the difference between individual commutes increases by a certain amount and household commuting distance does not increase by the same amount, or if it decreases, it can be concluded that individual commute distances are substitutes. However, a commuting trade-off can only occur when one worker increases their share of the household commuting distance in order to reduce their partner’s commute distance (illustrated in Figure 5.1). Therefore, if an inverse relationship is observed between household commuting distance and the difference between individual commutes, then this is an indication that two-worker households make commuting trade-offs.
Figure 5.1: Commuting trade-offs

5.3 Study Area and Data

The second step of phase one of this research examines the GTA, which is comprised of the census divisions of Toronto, Durham, Halton, Peel, and York (illustrated in Figure 5.2). It covers 7,200 square kilometers (Hodge and Robinson, 2001) and its population in 2016 was 6.4 million (Statistics Canada, 2017). The GTA is likely to be the fastest growing region in the Province of Ontario, with its population projected to be 9.6 million by 2041, which represents a 50 percent increase in population from 2016 (Ontario Ministry of Finance, 2017a). Within the GTA, there is a notable concentration of residential and business areas in the City of Toronto, which is considered the most significant central business district in the region. Its significance is reflected in the relatively higher quality public transportation network that serves Toronto. In surrounding regions, there is notably less public transit and more auto-oriented infrastructure. The overall public transportation network in the GTA is comprised of eight separately governed local transit agencies and one regional transit provider (Metrolinx, 2008). There is a high number of cross-regional commuting trips (one in four trips in the GTA and Hamilton) made by GTA residents
and the existing transportation network lacks the ability to support those trips, therefore, making those trips unattractive and not financially feasible (Metrolinx, 2008).

Figure 5.2: The Greater Toronto Area

This step of the research uses data from a stated-adaptation survey entitled Car and Home Ownership decisions in the face of Increasing Commuting Expenses (CHOICE) (Papaioannou and Habib, 2014). The CHOICE survey collected mobility tool ownership, home relocation, and home location choices from GTA households with at least one cross-regional commuter. All interviews were conducted for this survey between March and April 2014. The survey consisted of a revealed preference (RP) component which collected socio-demographic information and retrospective housing and vehicle ownership information, as well as a stated preference (SP) component that included two different experiments, SP1 and SP2.

In SP1, respondents were presented with a maximum of four scenarios of hypothetical commuting costs. In each subsequent scenario, commuting costs were significantly increased to induce households to adjust their mobility tool bundles as well as to change home location. If at any point in the scenarios, commuting costs were considered excessive, respondents could choose to relocate their residence to mitigate that cost. After completing SP1, either by voluntarily choosing to relocate or working through all four scenarios, respondents were asked to
complete SP2. The purpose of SP2 was to have respondents choose a new residential location in reaction to the commuting cost increase in SP1. The data in SP2 about households’ new home locations are used for this step of the research. The household location choices revealed in SP2 provide the basis for investigating commuting trade-offs between individuals in two-worker households.

The detailed data regarding mobility tool ownership and home relocation choices in SP1, as well as the home location choices in SP2, are used in the next phase of the research. The details regarding the design of the CHOICE survey including the commuting costs associated with the scenarios in SP1 are described in Chapter six.

A total of 413 households completed the full survey questionnaire. Of this sample, a total of 90 households had two out-of-home workers and thus this subset is used for empirical investigation in this step of the research. Given that two-worker households only make up about 28 percent of all households in Toronto, it is understandably difficult to obtain a large sample of survey responses for two-worker households, especially for a SP survey designed to collect detailed data. The central limit theorem requires a minimum of 30 records for a normally distributed sample. For the purpose of this study, the sample size of 90 is considered adequate, especially considering that a stratified sampling strategy was utilized for collecting survey responses which minimizes sampling error.

Some respondents reported that their households had more than two workers. In these cases, the second worker in the respondent’s household is defined as the individual who makes the highest income from the remaining workers (excluding the respondent). This is based on the rationale that the higher income individual likely contributes the most to household expenditures and has a larger impact on household decision making. Table 5.1 provides the definitions and numerical summaries of all variables used in the final specification of the models. There are four geometric variables that describe the spatial configuration of two-worker households, two of which have been introduced in Chapter four: household commuting distance and angle. In this step of the research, two additional variables are used:

1) Difference between longest and shortest individual commutes; and
2) Distance between workplace1 and workplace2.
As previously explained, the variable difference between longest and shortest individual commutes is used to investigate commuting trade-offs between individuals in two-worker households. This variable is calculated using respondents’ existing workplace locations and chosen home locations in SP2. This variable considers the Euclidean home-to-work distances rather than network distance since the collected stated preference data does not identify which specific mode each individual worker will choose in the stated preference scenarios. The variable distance between workplace1 and workplace2 is calculated using the existing workplace locations of both workers as reported in the survey.
Table 5.1: Definition and numerical summary of variables in models

<table>
<thead>
<tr>
<th>Definition</th>
<th>Minimum</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household commuting distance</td>
<td>5.52</td>
<td>39.98</td>
<td>51.89</td>
<td>191.22</td>
</tr>
<tr>
<td>Household income</td>
<td>57,500</td>
<td>137,500</td>
<td>139,194</td>
<td>250,000</td>
</tr>
<tr>
<td>Size of current home</td>
<td>397</td>
<td>1600</td>
<td>1730</td>
<td>4500</td>
</tr>
<tr>
<td>Owns current home</td>
<td>0/0</td>
<td>0/0</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>Angle</td>
<td>0.342</td>
<td>33.30</td>
<td>49.94</td>
<td>147.74</td>
</tr>
<tr>
<td>Difference between longest and shortest commute distances</td>
<td>0.197</td>
<td>9.72</td>
<td>12.86</td>
<td>71.1</td>
</tr>
<tr>
<td>Distance between workplace1 and workplace2</td>
<td>0.3</td>
<td>17.75</td>
<td>20.38</td>
<td>71.6</td>
</tr>
</tbody>
</table>
5.4 Econometric Modelling Framework

This research presents two models of *household commuting distance* including a Cobb-Douglas log-linear model and a multi-level random intercept-only model. In both models, the dependent variable $D$ (*household commuting distance*) is expressed as a function of housing attributes, household income, and the geometric variables.

The first model presented in this research is the Cobb-Douglas log-linear model in which the natural logarithm of the dependent variable is expressed as a function of the natural logarithms of independent variables. Two major advantages of this model are that the estimated coefficients of variables represent their corresponding elasticities with respect to the dependent variable and that its formulation resembles the demand function associated with the Cobb-Douglas utility equation (Oum, 1989). Equation 1 presents the specification of this model:

$$ ln(D) = \beta_o + \sum \beta_i \ln(x_i) + \sum \gamma_j y_j \quad (1) $$

Here, $D$ is the dependent variable *household commuting distance*, $\beta_o$ is the intercept of the model, $\beta_i$ refers to the vector of coefficients corresponding to the set of continuous independent variables $x_i$, and $\gamma_j$ refers to the vector of coefficients corresponding to the set of dummy independent variables $y_j$. The final model is estimated using the ordinary least squares regression method using the “lm” package in the statistical software “R”.

Classical regression models do not take into account repeated observations or variation across groups of data. The ability to model variation across groups is a critical feature that distinguishes multi-level modelling from classical regression (Gelman and Hill, 2007). The SP data used in this study inherently has a multi-level structure, whereby households can be grouped into categories based on whether they live in urban or suburban locations. To model the potential variation across these groups, the households in the data are grouped into five geographic areas delineated by municipal boundaries. These five groups include the City of Toronto, and the suburban regional municipalities of Durham, York, Peel, and Halton. The rationale to model the variation across these groups is based on the concept that differences exist in commuting patterns...
between urban and suburban households due to factors such as lifestyle preferences and different land-use characteristics.

Therefore, a two-level model is used, in which the upper level represents the geographic areas where households reside and the lower level corresponds to the households. The following is the multi-level random intercept model in which the coefficient that varies across groups is the model intercept $\alpha$.

$$y_i = \alpha_{j[i]} + \beta_1 x_{i1} + \beta_2 x_{i2} + \varepsilon_i \quad i = 1, \ldots, N, \quad j = 1, \ldots, J \quad (2)$$

$$\alpha_j = \mu_\alpha + \eta_j, \quad \text{with} \quad \eta_j \sim N(0, \sigma^2_\alpha) \quad j = 1, \ldots, J \quad (3)$$

Here, $y_i$ is the observed value of household commuting distance corresponding to observation $i$, $x_{i1}$ is the $i^{th}$ element of vector $x_1$ which represents the set of continuous independent variables, $x_{i2}$ is the $i^{th}$ element of vector $x_2$ which represents the set of dummy independent variables, $\beta_1$ is a set of coefficients corresponding to $x_1$ and $\beta_2$ is a set of coefficients corresponding to $x_2$. $\alpha_j$ represents the model intercept of group $j$. The intercept $\alpha_j$ is constant for all observations within a group while varying between different groups (i.e. City of Toronto, Region of Durham). $\varepsilon_i$ and $\eta_j$ are independent households and group error terms that follow a normal distribution with mean 0 and variance $\sigma^2$.

In order to determine the elasticities of the independent variables, equation two is expressed in a log-linear format:

$$\ln(y_i) = \alpha_{j[i]} + \sum \beta_1 \ln(x_{i1}) + \sum \beta_2 (x_{i2}) \quad i = 1, \ldots, N, \quad j = 1, \ldots, J \quad (4)$$

Development of the log-linear random intercept model follows a process whereby the model is built up gradually. First, a baseline generalized least squares model, denoted as model1, is developed. In model1, household commuting distance is expressed only as a function of an intercept. Second, a model denoted as model2 is developed, in which household commuting distance is expressed as a function of the intercept but allows the intercept to vary across different groups in the data (i.e. City of Toronto, Region of Durham). The Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and log-likelihood values are compared.
between these two models. Since the AIC, BIC, and log-likelihood values decrease from model1 to model2, this is an indication of a better fit of the model. Therefore, a multi-level structure is used in the model. Finally, the multi-level random intercept model, denoted as model3, is estimated in which *household commuting distance* is expressed as a function of several independent variables. The AIC, BIC and log-likelihood values for all three models are shown in Table 5.2. The log-likelihood values of the models are compared using a chi-square difference test. The chi-square value obtained has a reasonable level of significance. Based on the results, model3 is determined to be the best fit to the data and is therefore used in the ensuing results discussion.

Table: 5.2: AIC, BIC, and log-likelihood ratio test results

<table>
<thead>
<tr>
<th></th>
<th>AIC</th>
<th>BIC</th>
<th>Log-Likelihood</th>
<th>Test</th>
<th>Likelihood ratio</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>199.359</td>
<td>204.359</td>
<td>-97.68</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Model 2</td>
<td>169.728</td>
<td>177.228</td>
<td>-81.86</td>
<td>Model 1 vs 2</td>
<td>31.63</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Model 3</td>
<td>85.392</td>
<td>107.891</td>
<td>-33.70</td>
<td>Model 2 vs 3</td>
<td>96.34</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

5.5 **Empirical Investigation**

A summary of the Cobb-Douglas and multi-level random intercept models is presented in Tables 5.3 and 5.4. The final models include variables that are statistically significant and have intuitive signs. The 95 percent confidence limit for one-tailed tests (critical *t*-statistics value of 1.64) is used to identify the statistical significance of the estimated parameters. One-tailed tests are performed in accordance with the *a-priori* intuition and theoretical understanding regarding the factors that may affect *household commuting distance*. The final models employ the same independent variables; however, the variables have slightly greater coefficient values in the Cobb-Douglas model than in the multi-level random intercept model. The multi-level model accounts for group-level variation by allowing the model intercept to vary across the geographic areas where two-worker households reside. For example, the model intercept for the City of Toronto is 1.9342, while for the Region of Durham the intercept is 2.2742. The mean of all of the intercepts is 2.1132.
### Table 5.3: Cobb-Douglas model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>t-stats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.5467</td>
<td>1.673</td>
</tr>
<tr>
<td>ln Household income ($$$)</td>
<td>0.2251</td>
<td>1.726</td>
</tr>
<tr>
<td>ln Size of current home (ft$^2$)</td>
<td>-0.2270</td>
<td>-2.379</td>
</tr>
<tr>
<td>Owns current home (dummy)</td>
<td>0.2892</td>
<td>2.181</td>
</tr>
<tr>
<td>ln Angle</td>
<td>-0.5775</td>
<td>-14.495</td>
</tr>
<tr>
<td>ln Difference between longest and shortest commute distances (km)</td>
<td>-0.2260</td>
<td>-4.522</td>
</tr>
<tr>
<td>ln Distance between workplace1 and workplace2 (km)</td>
<td>0.8480</td>
<td>10.710</td>
</tr>
<tr>
<td>Multiple R-squared</td>
<td>0.7454</td>
<td></td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>0.727</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5.4: Multi-level random intercept model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>t-stats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.1132</td>
<td>1.474</td>
</tr>
<tr>
<td>ln Household income ($$$)</td>
<td>0.2299</td>
<td>1.870</td>
</tr>
<tr>
<td>ln Size of current home (ft$^2$)</td>
<td>-0.1676</td>
<td>-1.801</td>
</tr>
<tr>
<td>Owns current home (dummy)</td>
<td>0.2330</td>
<td>1.850</td>
</tr>
<tr>
<td>ln Angle</td>
<td>-0.5169</td>
<td>-12.253</td>
</tr>
<tr>
<td>ln Difference between longest and shortest commute distances (km)</td>
<td>-0.2203</td>
<td>-4.695</td>
</tr>
<tr>
<td>ln Distance between workplace1 and workplace2 (km)</td>
<td>0.7650</td>
<td>9.759</td>
</tr>
</tbody>
</table>

**Fixed effects**

**Group**

- City of Toronto: 1.9342
- Region of Durham: 2.2742
- Region of York: 2.0969
- Region of Peel: 2.0415
- Region of Halton: 2.2194
The positive value of the coefficient for *household income* suggests a positive association with *household commuting distance*. This finding is perhaps intuitive as higher income households have greater financial capabilities to incur greater commuting costs associated with living farther from workplaces. This result is also consistent with Alonso’s (1960) bid-rent theory which states that higher income households are more interested in maximizing utility gained from living in larger spaces of land and these are less impacted by commuting costs. The variable *size of current home* represents the total floor area of the respondents’ current homes. The estimated coefficient for this variable has a negative value, suggesting an inverse relationship between home size and commuting distance. A potential explanation for this finding is that households with larger homes dedicate a larger proportion of their household budget to home costs and therefore are sensitive to increases to commuting costs as presented in the survey. These household are likely to relocate in order to reduce their commuting distance and subsequently lowering household commuting costs. The variable *owns current home* is a categorical variable which represents the tenure of a household’s current residence. The estimated positive coefficient of this variable suggests a positive association between home ownership and *household commuting distance*. The explanation for this finding is similar to that of the variable *household income*, which is that home ownership is often tied to higher household income and therefore these households are less likely to be impacted by increased commuting costs.

The geometric variables used in this model describe the HWSC of two-worker households. It is important to study the effects of these variables as it provides a different method of assessing the influence of land-use on household commuting distance and consequently travel demand. The modelling results indicate that the estimated coefficient for *angle* has a negative value. This confirms the finding described in Chapter four, which is that an inverse relationship exists between *angle* and *household commuting distance*. This step of the research establishes that this relationship also exists in the context of the GTA. The explanation for this relationship is perhaps related to the urban environment of the GTA, namely the suburban sprawl which yields high concentrations of low-density residential areas in the urban periphery while the majority of employment opportunities are concentrated in the central business district. In this scenario, an inverse correlation between *household commuting distance* and *angle* is expected (refer to Figure 5.1).
The estimated coefficient for the second geometric explanatory variable *distance between workplace1 and workplace2* has a positive value, suggesting a positive association between total commute distance and the physical distance between the two workplaces. This finding is intuitive and suggests that households whose workplaces are farther apart also have longer combined commuting distances.

The estimated coefficient for the variable *difference between longest and shortest commute distances* has a negative value, indicating an inverse relationship with *household commuting distance*. This suggests that commuters in two-worker households trade off their individual commute distances and, in that process, reduce total household commute distance (refer to Figure 5.3). Recall that a commuting trade-off occurs when one worker incurs a longer proportion of the household commute distance in order to allow for the second worker to reduce their individual commute. However, an increase in the difference between individual commutes can also occur when total household commute distance increases. Therefore, a trade-off only occurs when the increase in the difference between individual commutes leads to a reduction in total household commute distance. As per the modelling results, households will trade off individual commute distances such that a 1 percent increase in the difference between individual commutes results in a 0.22 percent reduction in total household commute distance. Since, as the increase in the difference between individual commutes is positively associated with a reduction in household commute distance, it can be concluded that one worker increases their individual commute distance while the other worker reduces theirs.
Figure 5.3: Commuting trade-off and inverse relationship
5.6 Policy Implications

The movement of people in an urban environment is an important consideration for policy makers and the home-to-work commute contributes a significant proportion to that movement on a daily basis. Two-worker households comprise a significant and growing portion of GTA households and, as such, their home location decisions relative to where they commute to for work, are important considerations when planning for current and future urban activity systems. Two-worker households are unique in that they perform two home-to-work commutes from a single home location and therefore, that home location choice may be especially important when planning for the movement of people in an urban environment.

A general and longstanding policy directive of transportation and land-use planners in urban regions such as the GTA is to reduce the amount of travel by automobiles and encourage the use of active transportation modes. Long commute distances, necessitated by isolated land-uses, are a hindrance to that objective. By focusing on mixed-use development, urban regions can move away from the isolation of land-uses and in terms of the home-to-work commuting issue, planners look to achieve a jobs-housing balance. Jobs-housing balance has been the topic of much research and is generally achieved when there is heterogeneity between employment locations and the home locations of workers (Horner and Murray, 2003). Many have argued that a jobs-housing balance is not achievable because of two-worker households since they are unable to locate near both workplaces (Giuliano, 1991; Giuliano and Small, 1993; Levine, 1998; Dieleman et al., 2002).

This research challenges that argument by revealing that two-worker households will adjust their home locations in order to be closer to one of the work locations. Workers in a two-worker household will make commuting trade-offs such that one worker will incur a higher individual commute for the second worker to reduce their work commute. Our study finds that by making commuting trade-offs, two-worker households are achieving some level of a jobs-housing balance by locating closer to one of the two work locations. In making trade-offs, this research also reveals that two-worker household are achieving the above described overarching policy directive of reducing total household commute. Policy makers can continue to promote jobs-
housing balance in the urban environment as a method of reducing commuting distance and reducing the negative side effects associated with daily long-distance commutes by car (e.g. traffic congestion and pollution).

5.7 Chapter Summary

This chapter examined commuting trade-offs of two-worker households using Cobb-Douglas and multi-level models of household commuting distance. The models used SP data collected from households in the GTA. The modelling results revealed an inverse relationship between household commuting distance and the difference between longest and shortest individual commutes, which confirms that two-worker households make commuting trade-offs in order to reduce their overall commuting distance. From this result, it can be concluded that some level of jobs-housing balance is achievable for two-worker households since individual workers are willing to move closer to one work location. Therefore, it may be concluded that two-worker households are not a hindrance to land-use policies that encourage jobs-housing balance, despite the challenge of two separate work locations.

This chapter concludes phase one of the research which focused on specific land-use and transportation interactions in the context of two-worker households. First, Chapter four examined the impact of commuting modal accessibility on the HWSC and established that higher modal accessibility leads to a more optimal HWSC in respect of commuting distance. A transportation policy implication derived from that finding was to improve the coverage of public transit service. However, there are other factors which may hinder the optimal HWSC, especially for two-worker households that face the dual constraint of two work locations. Therefore, Chapter five examined commuting trade-offs between individual workers and concluded that households will relocate in order to trade-off individual commute distances such that one worker incurs a higher individual commute to allow the second commuter to reduce their commute distance. Accordingly, land-use policies which improve opportunities for jobs-housing balance may be effective for two-worker households.

This research acknowledges the influence of economic factors in these two systems. Accordingly, Chapter six presents phase two of the research and examines the influence of
increasing commuting costs on mobility tool ownership, residential mobility and home location choices.
CHAPTER 6

6 Mobility Tool Ownership, Home Relocation, and Home Location (relative to workplaces) Choices in the Context of Rising Commuting Costs

6.1 Chapter Overview

Phase two of the research is presented in this chapter which focuses on the context of rising commuting costs. This chapter presents the details of the CHOICE survey conducted in the GTA and uses its data to examine transportation and land-use choices in the context of increasing commuting costs. Two discrete choice models are developed to examine mobility tool ownership, home relocation, and home location relative workplaces. This chapter is organized into the following sections: Section 6.2 briefly introduces this study and the motivation. Section 6.3 provides an overview of the study area, detailed review of the survey design, and a descriptive analysis of the data used for modelling. Section 6.4 outlines the econometric modelling framework, and Section 6.5 presents the modelling results. Section 6.6 discusses the policy implications arising from the results. A summary of the chapter is presented in Section 6.7.

6.2 Introduction

This phase of the research examines land-use and transportation interactions in the context of rising commuting costs. It is commonly recognized that there is a two-way interaction between land-use and transportation systems. Current studies often evaluate the reverse impact of transportation demand/behaviour on land-use through accessibility measurements. While changes to the land-use system (built environment) can have palpable effects on travel demand in short periods of time, the transportation system impacts on land-use occur at a much slower rate. As such, the latter can often be overlooked by revealed preference travel and housing survey datasets. However, it is imperative to have a proper understanding of both sides of the transportation and land-use interaction.
Iacono et al. (2008) indicates that accessibility is usually defined as the influence of transportation infrastructure through some measure of access based on time, distance or cost. However, most studies consider a narrow range of travel costs and therefore may not be able to fully capture the factors that trigger residential mobility. To address this issue, this research using data from the CHOICE survey, which relies on stated preference hypothetical scenarios of increasing commuting costs. The first model is developed to jointly examine residential mobility and changes to mobility tool ownership while considering influences of the transportation system by way of significant increases to household commuting costs. The second aspect of this research evolves from the inducement of residential mobility and examines the home location choices of households relative to their workplace locations, namely whether households choose to stay in, move closer to, or farther from their workplace regions. The motivation of the second model is to understand the influence of changes to the transportation system on the land-use, namely the direction of movement of household in reference to their current workplace locations.

6.3 Study Area, Survey Design and Descriptive Analyses

6.3.1 Study Area

The second phase of the research uses the CHOICE survey data (Papaioannou and Habib, 2014) which was collected from households in the GTA. Accordingly, the study area for this research is the same as that described in Chapter 5, which also uses data from the CHOICE survey. Therefore, initial details of the study area are set out in section 5.3. It is also relevant to note that the GTA is one of North America’s fastest growing economic regions with a workforce of over three million people (Invest Toronto, 2015). Over the past decade, the GTA has undergone a housing boom supported by the population growth which has resulted in issues respecting housing affordability. Low-density development expanded outwards from that centre (City of Toronto) supported by higher income households who wished to move out of the dense core and into sparsely populated areas, single-family detached homes and auto-centric neighbourhoods.

6.3.2 Survey Design

This phase of the research presents the details of the CHOICE survey which is initially introduced in Chapter five. The CHOICE survey collects mobility tool ownership, home relocation, and home
location choices from GTA households with at least one cross-regional commuter. The survey consists of a revealed preference (RP) component, which collects socio-demographic information, characteristics of typical commuting trips, and retrospective housing and vehicle ownership information, as well as a stated preference (SP) component with two different experiments, namely SP1 and SP2. Table 6.1 summarizes the structure of the data collected in the survey and how the variables are grouped for modelling:

Table 6.1: SP1 & SP2 data collection

<table>
<thead>
<tr>
<th>CHOICES</th>
<th>SCENARIOS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>FUEL COST</td>
<td>$1.25/L</td>
</tr>
<tr>
<td>MOBILITY TOOL OWNERSHIP</td>
<td>1. Do nothing</td>
</tr>
<tr>
<td></td>
<td>a. Switch vehicle type (subcompact, midsize, large suv or pickup)</td>
</tr>
<tr>
<td>HOME RELOCATION</td>
<td>1. Stay at Current Location</td>
</tr>
<tr>
<td>SP2 HOME LOCATION</td>
<td>1. Stay in Current Home Location Region</td>
</tr>
</tbody>
</table>

In SP1, respondents are presented with a maximum of four scenarios and are requested to select a mobility tool bundle given the existing commuting costs associated with their current home and work locations. Scenario one represents the status quo where households can choose their mobility tool ownership and/or relocate under existing conditions. In scenario two, respondents are presented with new conditions, specifically increased commuting costs, and have the option to change their mobility tool ownership and/or relocate. The same occurs in scenarios three and four. However, after each scenario, only those respondents who choose to not relocate are presented with the subsequent scenario, which entails greater increases to the commuting costs. If at some point the commuting costs are perceived to be excessive, the respondent has the option to relocate their residence. A sample of the SP1 experiment is provided in Figure 6.1.
As part of the mobility tool bundle, respondents can choose different combinations of car type, fuel technology, and transit pass ownership. Respondents can examine these different combinations and the resulting cost associated with a particular mobility bundle (see Table 6.1). For modelling purposes, respondents’ mobility tool choices are categorized into two alternatives – 1) change mobility tools; or 2) no change (do nothing). Since the objective of the survey design is to capture the tradeoffs between commuting costs and residential mobility, the commuting costs are increased significantly to induce households to make changes to not only their mobility tools.
but also their home locations. At the time of the survey (September 2013) the fuel price in Toronto was approximately $1.25 per litre. Therefore, to generate commuting prices in the hypothetical scenarios, fuel prices are doubled, tripled and quadrupled in scenarios two, three and four, respectively.

In addition to auto costs, transit fares are determined for the four scenarios. However, the increase in transit fare cannot be of the same magnitude as the ones used for auto costs. Cross-regional transit trips can be quite costly and doubling, tripling or quadrupling transit fares would make transit unreasonably costly for most people. Therefore, a relationship is established to determine how fuel prices affect transit fares. Historical data are compiled for price per barrel of gasoline and the cost for the Toronto Transit Commission monthly pass since 1990 and adjusted for inflation. Different formulations are used to determine which one best explains the relationship between fuel price and transit fare. A third-degree polynomial equation is the best fit and is used to determine the percentage increase to transit fare for the various scenarios.

After voluntarily choosing to relocate, or after completing all four scenarios of SP1, respondents are to complete SP2. In SP2, respondents are asked to choose a new residential location by reviewing maps and selecting the desired region, city or township, and neighbourhood. Respondents are presented with qualitative neighbourhood characteristics in addition to housing prices of typical dwellings in the neighbourhood. In SP2 respondents consider average housing prices for each neighbourhood, for different dwelling types (detached, townhouse, apartment) and different number of bedrooms (one, two, three, four or more) that are for rent or for sale. A dataset of these averages was established for the CHOICE survey by obtaining the rental prices for units listed in the GTA in September 2013 and by obtaining the sale prices for housing units listed in the GTA in August 2013. Respondents are able to review these neighbourhoods, dwelling attributes and the associated costs and decide if they meet household needs, otherwise, they may continue searching elsewhere. A sample of the SP2 experiment is provided in Figure 6.2. For this phase of the research, only the data of the chosen home location areas are used in order to assess if there are any push/pull factors that influence the movement of households closer to or farther from their existing work locations.
Figure 6.2: Excerpt of SP2 of CHOICE survey
6.3.3 Descriptive Analyses

6.3.3.1 The Respondents

This phase of the research examines mobility tool ownership, home relocation and home location decisions of households. A total of 413 households fully completed the initial part of the SP questionnaire. Households across the GTA are represented in this data, with 32 percent currently residing in Toronto, 22 percent in York Region, 13 percent in Durham Region, nine percent in Halton Region, and 24 percent in Peel Region. A large proportion of the households live in single detached units (57 percent) and of those households, 55 percent own two or more vehicles. Single detached dwelling types and high automobile ownership are two characteristics that are strongly tied to suburban development and sprawling urban form. One might conclude that a significant proportion of the households involved in this study are suburban dwellers. In terms of tenure, 82 percent of households own their current residence while 14 percent of households rent their current residence. The household income of 43 percent of respondents is considered high income (more than $100,000); 39 percent fall into to medium income group ($60,000 - $100,000); and 18 percent are considered low income (less than $60,000). Income is an important factor in this research since the current financial standing of households may have significance for the actions they take in order to deal with the increasing transportation costs presented in the scenarios. Of the original 413 households presented with scenario one, 372 households (90 percent of all households) moved on to scenario 2. From scenario two, 309 households (75 percent of all households) moved on to scenario 3. After scenario three, only 255 households (62 percent of all households) remained to be presented with scenario four.

6.3.3.2 Changes to Mobility Tool Ownership

In the SP1 experiment, households are presented with scenarios in which they can choose their preferred mobility tools. Households have the option of doing nothing or changing their mobility tools, which can include any of the following changes: switching vehicle type and/or fuel type as well as changing transportation mode. Households who made any one of these changes are grouped together. Figure 6.3 shows the number of households across each scenario that chose to make changes to the existing mobility tools in the baseline scenario.
Figure 6.3: Number of households that changed mobility tools

In scenarios two, three and four, households are faced with sequential increases in transportation costs. It is observed that as costs increase, households are more willing to make some change to their mobility tool ownership. In scenario two, fuel prices increased by 100 percent from the baseline cost established in scenario one ($1.25/L to $2.5/L) and 39 percent of the households in scenario two mitigated that cost by changing their mobility tool ownership. In scenario three, fuel prices increased by 200 percent from the baseline cost established in scenario one ($1.25/L to $3.75/L) and 42 percent of the households in scenario three mitigated that cost by changing their mobility tool ownership. Finally, in scenario four, fuel prices increased by 300 percent from the baseline cost established in scenario one ($1.25/L to $5/L) and 45 percent of the households in scenario four mitigated that cost by changing their mobility tool ownership. It is important to note that the sample size decreases in each scenario as some households choose to relocate and are therefore ineligible to participate in the subsequent scenario.

6.3.3.3 Home Relocation

Also in the SP1 experiment, households are presented with the option to change their home location in order to mitigate travel costs resulting from rising fuel prices. Figure 6.4 shows the number of households across the four scenarios that choose home relocation. In both scenarios two and three, only 17 percent of households in each of these scenarios choose to change their home location. It is important to note that these percentages are based on a decreasing sample
size in each scenario. In scenario 4, despite a 400 percent increase to transportation costs from the baseline scenario, only 23 of the remaining 255 households (nine percent) choose to relocate. Accordingly, it is hypothesized that there may be a sense of permanency to home locations and that stress on the household budget, in the form of increasing fuel costs, cannot induce households to relocate.

![Figure 6.4: Number of households that changed home location](image)

There may be several reasons for the decision to stay in the current home location despite increasing transportation costs. Our *a-priori* hypothesis is that households with different income levels may be more or less sensitive to cost increases and that household income is a significant factor influencing the choice to relocate.

### 6.3.3.4 Combined Choice of Mobility Tools and Home Relocation

An important aspect of the SP1 experiment is the recognition of a household’s ability to make combined decisions concerning their mobility tool ownership and home relocation. As such, the households involved in this study are presented with four scenarios and requested to choose one of the following four combinations: (1) keep mobility tools and stay at home location; (2) change mobility tools and stay at home location; (3) keep mobility tools and change home location; and (4) change mobility tools and change home location. Figure 6.5 shows the percentage of
households in each scenario that choose each of these options. It is important to note that the total number of household in each scenario is reduced.

![Figure 6.5: Relocation and mobility tool ownership changes](image)

Across each of the scenarios, option one is the most selected while option four is the least popular. This means that the majority of households do not prefer the combined approach of mitigating increasing travel costs and instead choose to do nothing at all with their home location and mobility tool ownership that is established in scenario 1. Also, across each of the scenarios, options three and four are the least popular which means that households are unwilling to move their home locations and instead prefer to alter their mobility tool ownership as a means of mitigating increasing transportation costs. The unwillingness of households to change their home locations may be a result of the relative impact of transportation costs on the household budget. Intuitively, home costs (i.e. mortgage or rent) comprise a larger portion of the household budget than transportation costs. Making changes to a significant portion of the budget may be less desirable than altering mobility tools and their associated costs, which in comparison would have a less significant effect on the household’s budget.

Existing research (i.e. Habib et al., 2006) suggests that residential mobility is triggered by stressors or major life-cycle events, such as the birth/adoption/death of a household member,
marriage, separation, etc. Home relocation requires substantial effort and cost; therefore, it is not surprising to see a strong household inertia against home relocation. Home relocation entails costs associated with land transfer tax, realtor fees, and lawyer fees. Also, given the rapid increase of average home prices in the GTA, it is likely that home relocation will put a heavier financial burden on households even if a similar dwelling size and type is chosen.

Over the last three decades, the average real income in the GTA rose by 18 percent (in 2012 dollars), but real home prices increased by 80 percent during the same time period (Burda, 2013). Therefore, unaffordability has become a major issue since home ownership costs have steadily become a larger percentage of the household budget. The widening gap between incomes and average home prices is likely hindering the ability of households to relocate. In fact, the stated preference data indicates that of all households who decide to relocate, the average household income is substantially higher than households that do not relocate (i.e. $120,978 vs $93,394). This hypothesis is further tested by the combined choice model presented in this dissertation to assess the relationship between household income and residential mobility.

6.3.3.5 Home Location Choice relative to Workplace

The SP2 experiment is an in-depth analysis of home location choices, which compares current and chosen home locations. Respondents in the survey consider options for home locations by reviewing neighbourhood characteristics, dwelling attributes (i.e. type and cost) and commuting trip characteristics. The home location choices of respondents are compared to their existing home locations and then categorized based on whether their decision led to a reduction, increase or no change to their commuting distance. The data collected in SP2 is further categorized as follows: 1) those who live and work in the suburbs; 2) live in the suburbs and work in Toronto; 3) live and work in Toronto; and 4) live in Toronto and work in the suburbs. The respondents are categorized in this manner in order to generally gain insight into their commuting conditions namely distance. Of the 475 households who participated in the SP2 experiment, 43 percent (202 households) live and work in the suburbs, 27 percent (128 households) live in the suburbs and work in Toronto, 24 percent (113 households) live and work in Toronto, and seven percent (32 households) live in Toronto and work in the suburbs. These statistics are important for this research and are summarized in Figure 6.6.
In the SP2 experiment, respondents are asked to choose their preferred home location region, which are grouped into three categories (as indicated in Table 6.1). Of the participating households, 161 (34 percent) choose to stay in their current home location region; 110 (23 percent) choose to move closer to their workplace location; and 204 (43 percent) choose to move farther away from their workplace region. Therefore, a combined total of 77 percent of households do not choose to shorten their commute distance by relocating to a region closer to their current work location. The factors that would otherwise pull households closer to their workplaces may not be strong enough for respondents in this study.

The potential explanation for this observed pattern of relocation is perhaps tied to the previously noted widening gap between income and average home price in the GTA. The scarcity of developable land and the demand for housing in the GTA are some of the factors driving up the price of real estate. The links between housing demand and prices are both complex and dynamic. It is understood that people tend to prefer different types of housing at different life cycle stages. What is not well understood is how land prices near activity centers are impacting home relocation. In the GTA, attached and semi-detached houses located close to employment opportunities and amenities such as schools, parks and higher order transit, command much higher prices than homes with less access to amenities. For example, in April of 2013, the average price of a detached house in the City of Toronto was over $800,000, while in the suburban region outside of Toronto, the price was just under $600,000 (Burda, 2013).

The above raises the issue that prices are determined by supply and demand factors. The rapid increase in real estate prices has led to affordability issues resulting in higher income households occupying central areas and the more financially constrained households being pushed out to smaller dwellings or suburban locations. Home ownership can put a significant strain on the household budget. TD Bank (2015) estimates that nearly 40 percent of household income is allocated to mortgage payments, therefore making home ownership a significant budget constraint for the average homebuyer. Therefore, it can be hypothesized that high real estate prices in urban areas and the resulting increased stress on income is driving development outwards (suburbanization) where cheaper and more affordable housing may be found. Furthermore, since housing is a much higher cost than transportation, the majority of households in this survey likely choose to move farther away from their current workplaces in order to find
affordable housing and endure a higher transportation cost. This hypothesis is tested in the second model developed in this phase of the research.

Figure 6.6 further breaks down the statistics referenced above by household type. The most interesting results come from comparing the data of the households that live in the suburbs and work in Toronto and the households that live and work in Toronto. These household types have significantly different commuting conditions and therefore their choices in the SP2 experiment are also notably different. When comparing the three categories of home location choices for the households that live in the suburbs and work in Toronto, the choice to move closer to the workplace location is the most popular (46 percent of households). The opposite is the case for the households that live and work in Toronto. Of the three home location choices, the choice to move closer to the workplace location is the least popular (13 percent of households). While this may be simply attributed to geography, it also raises the possibility that the net benefit of reducing transportation costs by moving closer to work is not significant enough for those who live and work in Toronto as their commuting costs may already be comparatively low while their home costs are higher. Therefore, moving closer to reduce commuting costs is not a significant enough pull factor this type of household.

Figure 6.6: Home location choices by household type
6.4 Econometric Modelling Framework

Two household behaviours are modelled in this phase of the research: 1) combined home relocation and mobility tool choice, and 2) home location choice relative to existing workplace location. The first behaviour is examined by considering three different modelling formulations. The first model tested is the nested logit model (not presented here). The advantage of the nested logit model is that it allows for correlations between alternatives and it does not have the limitation of the independence from irrelevant alternatives (IIA) property. After empirical investigation of the nested logit model, it is found that the coefficient of the inclusive parameter is more than one, which suggests that the nesting structure is not appropriate. An alternative formulation is tested by inverting the hierarchy of the lower and higher nests (not presented here). The coefficient of the inclusive parameter for this alternative nest is also more than one, which reveals that the choices do not follow a nested decision structure (Train, 2009).

Another modelling approach tested in this research is the use of a multinomial formulation that examines pairs of home relocation and mobility tool ownership choices. This type of model is herein referred to as a “combined choice multinomial logit model” since each alternative consists of a bundle or pairings of choices. The following four alternatives, which are mutually exclusive and collectively exhaustive, are considered in this model: 1) keeping mobility tools and staying at current home location; 2) switching mobility tools and staying at current home location; 3) keeping mobility tools and leaving home location; and 4) switching mobility tools and leaving home location. The formulation of the combined choice multinomial logit model is as follows:

If $V_{mi}$ indicates the systematic component and $\epsilon_{mi}$ indicates the random component of the total utility of home relocation and switching mobility tool choice ($m$), then the utility of home relocation and switching mobility tool choice ($U_m$) for an individual ($i$) can be written as:

$$U_{mi} = V_{mi} + \epsilon_{mi}, \quad m = 1,2,3,4$$

(1)

$V_{mi} (\beta X_{mi})$ consists of $X_{mi}$ and $\beta$, where $X_{mi}$ is the vector of explanatory variables for alternative $m$ and $\beta$ is the associated vector of parameters. The random component follows an IID type I extreme value distribution. According to random utility maximization (RUM) theory, the
probability that an individual \( i \) selects alternative \( m \) can be presented as equation 2 (McFadden, 2001):

\[
P_{mi} = \frac{e^{V_{mi}}}{\sum_{m'=1}^{4} e^{V_{mi}}}
\]

(2)

The log likelihood function considering a total of \( N \) individuals with four alternatives can be written as follows:

\[
LL(\beta) = \sum_{i=1}^{N} \sum_{m=1}^{4} y_{mi} \ln(P_{mi})
\]

(3)

Here, \( y_{mi} = 1 \) if person \((i)\) chooses alternative \((m)\) and it is zero if the person does not choose that alternative.

The second model presented in this paper is a multinomial logit model consisting of three choices: 1) stay in the current home location region; 2) move closer to the workplace location; and 3) move farther from the workplace location. The model uses the SP data whereby respondents are requested to make home location choices. As noted previously in the descriptive analyses, of the three choices examined above, the most selected option is to move farther from current workplace location. This multinomial logit model tests whether certain factors influence the direction of home location choice relative to existing workplace and is formulated as follows:

If \( V_{mi} \) indicates the systematic component and \( \varepsilon_{mi} \) indicates the random component of total utility of home location \((m)\), then the utility of home location relative workplace location \((Um)\) for an individual \((i)\) can be written as:

\[
U_{mi} = V_{mi} + \varepsilon_{mi}, \quad m = 1,2,3
\]

(4)

\( V_{mi} (\beta X_{mi}) \) consists of \( X_{mi} \) and \( \beta \), where \( X_{mi} \) is the vector of explanatory variables including alternative \( m \) and \( \beta \) is the vector of parameters. The random component follows an IID extreme value type I distribution. According to RUM theory, the probability that individual \( i \) selects alternative \( m \) can be presented as equation 5 (McFadden, 2001):

\[
P_{mi} = \frac{e^{V_{mi}}}{\sum_{m'=1}^{3} e^{V_{mi}}}
\]

(5)
For the multinomial logit model, log likelihood function of a total of \( N \) individuals, each with three alternatives, can be written as follows:

\[
LL(\beta) = \sum_{i=1}^{N} \sum_{m=1}^{3} y_{mi} \ln(P_{mi})
\]  

(6)

Here, \( y_{mi} = 1 \) if Person \((i)\) choose Alternative \((m)\) and it is zero if the person does not choose that alternative.

6.5 Empirical Investigation

The final specifications of the models are selected by considering expected signs of variables and z- statistics of the parameters. A 95 percent confidence level (critical z-statistics value of 1.96) is used for investigating the statistical significance of parameters. Based on a theoretical understanding and in some cases a strong intuition regarding the effects of variables (whether positive or negative sign), one-tailed tests are performed. Some parameters with z-statistics lower than 1.96 are retained in the model given their importance in explaining behaviour and due to their expected signs. Goodness-of-fit (rho-square values) of the estimated models are calculated. A higher rho-square value indicates a better fit of the estimated model with the observed data. The results of the models are depicted in Tables 6.2 and 6.3.

6.5.1 Combined Home Relocation and Mobility Tool Ownership Choice

The combined choice model for home relocation and mobility tool ownership considers four alternatives. The first alternative is “do nothing”, which is the reference for the estimated model. The variables included for all four alternatives are indicated in Table 6.2. The dummy variable households with a transit pass represents households who have at least one worker with a transit pass. This variable has a positive coefficient for alternatives 2 and 4, which suggests that households with transit passes are more likely to respond to significant increases in transportation costs by switching mobility tools. This finding is intuitive as households who possess transit passes are likely adaptable to increasing fuel prices which impacts the costs of auto usage more substantially than public transit usage. These households perhaps utilize their transit pass over auto usage in the event of a significant increase in fuel prices.
The variable *home and transport costs* represents the sum of the monthly home costs (either rent or mortgage) and transport costs. This variable has a positive coefficient for alternative 4, which indicates that households faced with increasing home and transportation costs are more likely to make the combined choice to change mobility tools and relocate homes, perhaps in an effort to alleviate the strain on the household budget. The variable *logarithm of household income* has a positive coefficient for alternatives 2 and 4, which indicates that households with greater incomes are more likely to make changes to their mobility tools and/or home location. This finding supports the *a-priori* hypothesis indicated in the descriptive analyses, which is that despite the general reluctance towards household relocation, higher income households are more able to sustain the costs associated with relocation.

The dummy variable *single parent household* has a positive coefficient for alternative 2, suggesting that single-parent households are more likely to switch mobility tools and stay at the current home location. The dummy variable *household with kids* has a negative coefficient for alternative 2, suggesting that these households are less likely to switch mobility tools and stay at the current home location. The dummy variable *households with two or more vehicles* has a positive coefficient for alternative 2, suggesting that these households are more likely to switch mobility tools and stay at the current location. Multiple vehicle ownership suggests that these households are more auto-centric and are therefore highly impacted by increases to fuel prices, thus explaining their inclination to change their mobility tools.

The dummy variable *households with multiple commuters* has a negative coefficient for alternatives 2 and 4, both of which are choices that do not change mobility tools. Households with multiple commuters have greater travel demands, which may make them more reliant on their mobility tools and less inclined to make changes to them. Instead, these households are more likely to relocate in order to alleviate the financial burden of increasing transportation costs, as suggested by the positive coefficient of alternative 3.

The variable *area of current home* has a negative coefficient for alternative 3, which suggests that households living in larger homes are more likely to do nothing than make changes to their home location. There may be lifestyle and market factors at influence the decision to maintain current
home locations, including the desire for spacious homes and the inability to find similar size homes without drastic increases to their home costs.
Table 6.2: Combined choice model for home and mobility tool bundle

<table>
<thead>
<tr>
<th>Choice</th>
<th>Choice 1 (Keep current mobility tool bundle, &amp; stay in current home location)</th>
<th>Choice 2 (Change mobility tool bundle, &amp; stay in current home location)</th>
<th>Choice 3 (Keep current mobility tool bundle, &amp; change home location)</th>
<th>Choice 4 (Change mobility tool bundle, &amp; change home location)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>z - value</td>
<td>Parameter</td>
<td>z - value</td>
</tr>
<tr>
<td>Alternative Specific Constant</td>
<td>-</td>
<td>-</td>
<td>-5.09322</td>
<td>-2.74</td>
</tr>
<tr>
<td>Households with a transit pass</td>
<td>-</td>
<td>-</td>
<td>0.71159</td>
<td>3.53</td>
</tr>
<tr>
<td>Home and transport costs</td>
<td>-</td>
<td>-</td>
<td>0.00053</td>
<td>-2.47</td>
</tr>
<tr>
<td>Logarithm of household income</td>
<td>-</td>
<td>-</td>
<td>0.96632</td>
<td>2.45</td>
</tr>
<tr>
<td>Single parent household</td>
<td>-</td>
<td>-</td>
<td>0.42434</td>
<td>2.11</td>
</tr>
<tr>
<td>Households with kids</td>
<td>-</td>
<td>-</td>
<td>0.37692</td>
<td>-2.02</td>
</tr>
<tr>
<td>Households with two or more vehicles</td>
<td>-</td>
<td>-</td>
<td>0.73884</td>
<td>4.38</td>
</tr>
<tr>
<td>Households with multiple commuters</td>
<td>-</td>
<td>-</td>
<td>0.3306</td>
<td>-1.63</td>
</tr>
<tr>
<td>Area of current home</td>
<td>-</td>
<td>-</td>
<td>0.0005</td>
<td>-2.94</td>
</tr>
<tr>
<td>Rho-squared (against null model)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.5.2 Home Location Choice relative to Workplace

The home location choice model considers three alternatives: 1) stay in the current home location region (reference alternative); 2) move to a region that is closer to the workplace location; and 3) move to a region that is farther away from the workplace location. The regions considered in this model are the regional municipalities within the GTA, including Toronto, Durham, York, Peel, and Halton. The intent of this model is to provide insights about factors that “pull” or “push” households towards or away from the respective work locations. The above modelling approach is different than conventional home location choice models that model specific choices respecting home locations and dwelling types, which is a more appropriate for land-use forecasting.

The home location choice model in this research employs several variables which are selected based on intuition and theory. The model uses data from SP2 regarding the home location choices of the cross-regional commuters who are sampled in the survey. This group of the population commutes relatively long distances compared with inner city residents who work and live in the same municipality. Intuitively, commuting distance is likely an important factor in explaining the home location behaviour of the households in this study. Therefore, the variable distance to job is used in the model specification and represents the total household network distance to job by automobile (expressed in kilometres). The estimated parameter for distance to job is positive for alternative 2, which is intuitive since households who currently have longer commute distances can be expected to mitigate transportation costs by moving closer to their work locations. Conversely, the estimated parameter for distance to job is negative for alternative 3, which suggests that higher commuting distance decreases the likelihood of moving farther away from the work location. The variable area of current home is estimated with a positive coefficient for alternative 2, suggesting that households currently residing in larger homes are more likely to move closer to the workplaces. One possible explanation for this result is perhaps that these households are more sensitive to increases to their transportation costs since they already incur high costs associated with their large homes. Moving closer to their respective workplaces enables these households to relieve the transportation cost strain on their budget.
Table 6.3: Model of home location relative to workplace location

<table>
<thead>
<tr>
<th>Choice</th>
<th>Choice 1 (Stay in Current Home Location Region)</th>
<th>Choice 2 (Move Closer to Workplace Location)</th>
<th>Choice 3 (Move Farther Away from Workplace Location)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>z - value</td>
<td>Parameter</td>
</tr>
<tr>
<td>Alternative Specific Constant</td>
<td>-</td>
<td>-</td>
<td>1.199</td>
</tr>
<tr>
<td>Area of current home (square metres)</td>
<td>1.001</td>
<td>1.62</td>
<td>-</td>
</tr>
<tr>
<td>Distance to job (kilometres)</td>
<td>0.03748</td>
<td>3.64</td>
<td>-0.0187</td>
</tr>
<tr>
<td>Household income ($)</td>
<td>-1.0449</td>
<td>-1.56</td>
<td>0.695</td>
</tr>
<tr>
<td>Average property value price difference between work location and home location ($)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rho-squared (against null model)</td>
<td>0.0627</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-328.52189</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample size</td>
<td>319</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The variable *household income* is estimated with a negative coefficient for alternative 2 and positive coefficient for alternative 3, which supports the initial hypothesis set out in the descriptive analyses (section 6.3.3.5). This result suggests that higher income households are less likely to relocate closer to work and more likely to move farther away from work in the event of increasing transportation costs. This finding is consistent with Alonso’s (1960) theory regarding households’ bid-rent curves, in which higher income households are more interested in maximizing the utility associated with living on larger spaces of land and less affected by transportation costs. A finding of the previously reported combined choice model is that higher income is positively correlated with the choice to relocate. The home location model adds to that finding and indicates that higher income households are likely to move farther away from workplaces in the event of increasing transportation costs.

The variable *average property value price difference between work location and home location* (average property value difference) is estimated with a positive parameter for alternative 3. The positive sign indicates that higher prices at the workplace location influences households to locate farther away. This may perhaps explain the observed outward movement of households when making home location choices in the stated preference survey. This result can be further examined by considering the issue of unaffordability in the real estate market in the GTA. For over a decade, the GTA has been experiencing a significant housing boom. There are some negative impacts of that housing boom including lack of affordability. The Royal Bank of Canada (RBC) and the Pembina Institute conducted a study which revealed that in 2012, over 80 percent of GTA residents would give up a large home to live in a transit-friendly and walkable neighbourhood that allows for shorter commutes, however, more than 70 percent of residents also say that their current home location was chosen as a result of affordability rather than preference (Burda, 2012). Toronto Dominion (TD) Bank reports that the problem of home affordability is now affecting even high-income households in the homeownership market rather than the traditionally affected low-income households participating in the rental market.

As a result of home costs, households are carrying more debt and are highly sensitive to negative outside economic shocks (TD Bank, 2015), such as increased travel costs, which this study considers. Figure 6.7 shows the drastically increasing housing costs in the GTA over the past 15
years. Home prices and the associated affordability issues are not evenly distributed throughout the GTA. Between certain municipalities, there was more than a $200,000 difference in average home prices as reported in 2012 (Burda, 2013) and as a result, opportunities for home relocation are limited. The option to relocate to an area closer to the work location to reduce commuting costs may not be a viable one due to home prices around the work location. According to the RBC and Pembina Institute, households facing those circumstances are being “priced out” of the market (Burda, 2013). As a result, households may be moving outwards from central areas, where their workplaces are likely located, in search of more affordable housing.

Figure 6.7: GTA home prices (TD Bank, 2015)

6.6 Policy Implications

Understanding residential relocation, mobility tool ownership, and home location choices is crucial for integrated land-use and transportation planning. High auto usage is a common characteristic of households residing in sprawling urban regions, such as the GTA, in part due to the auto-dependence created by the dispersed built environment and roads and highway infrastructure. Households in the suburban sprawling areas of the GTA who have high auto
ownership levels may be especially sensitive to increases to their transportation costs. This research tests that sensitivity by examining households’ residential mobility decisions and the general direction of movement in urban regions. These household decisions provide insight into land-use and transportation interactions and the role of increasing transportation costs. Increases to transportation costs can come about in various ways, such as increases to fuel prices, road tolls, and car taxes. This research uses the scenario of increasing fuel prices and hypothesizes that drastic increases may induce household to move closer to urban centres, which therefore may initiate a process of reversing suburban sprawl. The results of this study reveal a general reluctance of households to relocate, as well as an outward movement of households precipitated by high real estate prices. Therefore, the issue of high real estate prices in central areas and the ensuing unaffordability are important considerations for policies aimed at mitigating further sprawl.

Toronto’s re-urbanization (i.e. a shift of growth to the city) began about three decades ago and was sparked by a market-driven condominium boom and a policy-driven redirection of growth to central areas. However, as revealed by our research, high real estate prices induce households to relocate farther from workplaces, thereby perpetuating urban sprawl. In countering the effects of urban sprawl, the focus of planning agencies is often improving public transportation, increasing densities and development of mixed land uses (City of Toronto, 2006, Ministry of Transit, 2006). Although these are all important policies (some of which are outlined previously in this research), the importance of affordability of housing cannot be overlooked. Housing unaffordability in the GTA has become such a significant issue that the Province has now stepped in with its Fair Housing Plan (Ontario Ministry of Finance, 2017b), which includes measures such as rent control, property tax control, and rebating development charges for affordable units. These measures are addressing the fundamental issue of unaffordability which should be considered in combination with transportation and land-use policies (i.e. improving transit and increasing density) in order to effectively mitigate suburban sprawl. This research highlights the influence of real estate prices on the outward movement of households and as such, it is concluded that housing affordability policies should be considered to limit that movement.
6.7 Chapter Summary

This chapter examined the impact of transportation on land-use through the lens of rising commuting costs. Commuting cost has been considered in existing research, however, a broad range of costs has not been sufficiently studied in order to determine its impact on land-use. Using stated preference data, discrete choice models were developed to better examine the factors that trigger changes to mobility tool ownership, residential mobility and home location choices relative to workplaces. A key finding of the combined choice model conducted in this phase of the research was that high income was positively correlated with the choice to relocate. Furthermore, a key finding of the second model (home location relative to the workplace) was that higher real estate price differentials between workplace and home locations induced households to move farther away from workplaces, thus perpetuating urban sprawl. A policy implication derived from these modelling results is that improving residential affordability, such as providing non-market driven housing opportunities, is essential to mitigating sprawl.

Phases one and two of this research examined the less-studied reverse impacts of transportation on land-use. A thorough examination of this two-way interaction also requires furthering the understanding of the impact of land-use on transportation, which the next phase of this research does by considering the context of transit-oriented development. Integrated land-use and transportation planning is essential to shaping urban regions in a socially, economically and environmentally sustainable way. Although transit-oriented development has been extensively studied, there is a gap in empirical research especially concerning its influence on travel choices. Phase three of this research focuses on filling that gap through empirical investigations.
CHAPTER 7

7  Relationship between Transit Ridership with Walk Access/Egress and Transit-Oriented Development

7.1  Chapter Overview

The first step of phase three of this research is presented in this chapter. Phase three focuses on the context of transit-oriented development (TOD). This first step investigates the relationship between characteristics of TOD and transit ridership via walk access/egress. This chapter is organized into the following sections: Section 7.2 introduces the motivation for this study. Section 7.3 provides an overview of the study area and data used for modelling. Section 7.4 outlines the econometric modelling framework, and Section 7.5 presents the modelling results. Section 7.6 discusses the policy implications arising from the results. A summary of the chapter is presented in Section 7.7.

7.2  Introduction

An integrated approach to land-use and transportation planning is required to reduce reliance on automobiles and improve the use of public transit and active transportation modes, all of which may be achieved with Transit-Oriented Development (TOD). TOD is a compact, mixed-use, pedestrian and cyclist friendly form of urban development that is oriented towards transit use. One outcome of TOD is an increase in transit riders walking to and from a central transit station to complete their journey. Although TOD has been the subject of much research, no empirical studies have investigated factors that affect transit ridership with walk as the station access and egress mode.

Another motivation for this research is the important strategy of the regional transit service provider in the Greater Toronto and Hamilton Area (GTHA) to increase the use of active transportation, specifically walking, to access all rail stations throughout the network (Metrolinx, 2013). Step one of phase three of the research empirically investigates the relationship between
certain characteristics of the urban environment, which are generally encouraged in TOD policy, and rail transit ridership with walk access and egress.

The empirical investigation uses both station-level attributes (such as frequency of feeder bus service to a rail station) and characteristics of the area surrounding GO Transit rail stations (such as residential and employment density). By examining these attributes, which are also characteristics of TOD, we can make inferences about their effects on rail ridership. Two separate models are estimated, including a rail trip production by walk access model and a rail trip attraction with walk egress model. By developing two separate models, this study identifies the unique factors that influence trip production and attraction. Most empirical studies on TOD employ trip generation models but do not isolate those trips that started or ended with walking. This step of the research focusses specifically on those types of trips to identify the influencing factors, which may not be the same for overall trip generation.

7.3 Study Area and Data

7.3.1 Study Area and Transit Context

The study area of this research is the GTHA, which covers an area slightly larger than the GTA which was the study area for other phases of research (step two of phase one and phase two). The GTHA includes the GTA and the municipality of Hamilton, which captures the coverage of the GO Transit service. The GTHA has an area of approximately 11,000 square kilometres with seven million people (GO Transit, 2015). It is one of Canada’s largest and fastest growing metropolitan regions and is also one of North America’s fastest growing economic regions with a work force of over three million people (Invest Toronto, 2016). Residents and jobs are spread out over the City of Toronto and the five surrounding municipalities of Hamilton, Peel, Durham, Halton, and York, as shown in Figure 7.1, with the highest concentration of both being in the City of Toronto.

Metrolinx is the regional transportation authority in the GTHA and is tasked with improving the coordination and integration of all transportation modes in the region. GO Transit, a division of Metrolinx, operates the regional public transit network in the GTHA. The GO Transit service consists of seven train lines and off-peak buses, all of which terminate at Union Station, which is
the largest and most important GO Transit station in the network and is located in downtown Toronto.

![GTHA and GO Transit rail lines](image)

Figure 7.1: GTHA and GO Transit rail lines

This research focuses on an 800-meter radius surrounding all GO Transit rail stations across the GTHA. Aside from Union Station, which is located in the City of Toronto and the hub of public transit activity in the GTHA, GO Transit rail stations are generally located in the suburban areas surrounding the City of Toronto. Land-use patterns and densities in these suburban areas are largely unsupportive of greater transit use. If traditional suburban land-use patterns and densities continue, GO Transit will face challenges in attracting sufficient customers to recover operating costs.
Over the past decade, the GTHA has undergone a housing boom supported by the population growth, which has resulted in issues with respect to housing affordability as discussed in the previous chapter (Burleton and Petramala, 2015). Development of the GTHA generally followed typical North-American urban sprawl, which consisted of an urban centre (which in this context is the City of Toronto) with a high concentration of residents and jobs. Low-density development expanded outwards from that centre supported by higher income households who wished to move out of the dense core and into sparsely populated areas, single-family detached homes, and auto-centric neighbourhoods. Today, each of the regions surrounding the City of Toronto has a notably less dense urban environment, yet over time they have evolved with higher density housing and concentrations of employment and amenity areas.

Transportation in the GTHA follows a similar pattern to the urban form, with a concentration of services in the City of Toronto and notably less public transit and more auto-oriented infrastructure in the surrounding regions. Today, transportation infrastructure is severely lacking and poses a potential hindrance to successful future development in the GTHA. The public transportation network in the GTHA consists of one regional transit agency (GO Transit) and nine independently governed local transit agencies. The rapid transit network is comprised of the GO Transit rail network and Toronto’s subway system. While cross-regional commuting is highly common for GTHA residents (one in four trips in the GTHA), the existing public transportation network lacks sufficient integration to effectively serve this travel market (Metrolinx, 2008a).

7.3.2 Data

The data used for the empirical investigation is extracted from the 2014 GO Rail Passenger Survey administered by Metrolinx (Metrolinx, 2014). The survey is part of an ongoing program undertaken by GO Transit to monitor ridership, market trends, and commuter travel behaviour. The survey provides information on inbound rail trips towards Union Station including trip origin, boarding GO Transit rail station, alighting GO Transit rail station, access mode, egress mode, and trip destination. A total of 14,572 complete trip records are available in the dataset. The distribution of the survey data along the seven rail corridors closely reflects the actual distribution of GO Transit inbound trips as measured by cordon counts. The sample dataset represents around two percent of GO Transit’s rail ridership.
As TOD is largely focused on improving the connectivity and walkability around transit stations, this research aims to study the factors that influence rail ridership with walk as the access/egress mode. Trips by walk as the access/egress mode are aggregated at the station level to allow for a station level analysis. The unit of analysis used in this research is based on the 10-minute walk or 800-metre radius surrounding a central transit station, which is established by TOD principles. Metrolinx has also established an 800-metre radius for its Mobility Hubs, which are subject to design guidelines that draw from TOD policy (Metrolinx, 2011). The total number of GO Transit rail stations is 64. To study the relationship between rail ridership by walk access/egress and TOD characteristics identified in the literature review, a comprehensive analysis is conducted on the rail stations’ characteristics and land-use attributes in the 800-metre radius or the walking catchment area. Supplemental data on street connectivity/walkability within 800 metres of GO Transit rail stations, transit accessibility, network distances and travel times to and from GO Transit rail stations, and transit (GO Transit rail and bus feeders) frequency are obtained from Metrolinx. In addition, employment density is calculated using data from the Canada Business Points and population density is calculated using CHASS data. Table 7.1 provides the definitions and numerical summary of all variables used in the final specification of the models.
Table 7.1: Definition and numerical summary of variables in models

<table>
<thead>
<tr>
<th>Definition</th>
<th>Minimum</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transit Ridership with walk access</strong></td>
<td>8</td>
<td>111</td>
<td>154</td>
<td>638</td>
</tr>
<tr>
<td>Number of trips that originated at station with walk access from home to station</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Population density</strong></td>
<td>1099</td>
<td>7946</td>
<td>8758</td>
<td>25680</td>
</tr>
<tr>
<td>Number of people residing within 800m radius of station</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AM Frequency</strong></td>
<td>2</td>
<td>8</td>
<td>9</td>
<td>44</td>
</tr>
<tr>
<td>Morning frequency of GO Rail service at the station</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AM Arrivals</strong></td>
<td>0</td>
<td>26</td>
<td>41</td>
<td>220</td>
</tr>
<tr>
<td>Number of morning local transit feeder buses servicing the station</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Walk Score</strong></td>
<td>13</td>
<td>66</td>
<td>62</td>
<td>99</td>
</tr>
<tr>
<td>Score out of 100 which represents walkability of stations' surrounding environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Parking Utilization</strong></td>
<td>0</td>
<td>97</td>
<td>82</td>
<td>118</td>
</tr>
<tr>
<td>Percentage of parking spaces occupied in the morning peak period</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Transit Ridership with Walk Egress</strong></td>
<td>1</td>
<td>17</td>
<td>67</td>
<td>1259</td>
</tr>
<tr>
<td>Number of transit trips that ended at station with walk egress (from station to destination)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Employment Density</strong></td>
<td>66</td>
<td>3521</td>
<td>4176</td>
<td>22192</td>
</tr>
<tr>
<td>Number of jobs within 800m radius of station.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Toronto Station</strong> (dummy variable)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>This is a dummy variable which takes the value of 1 if station is located in the City of Toronto or 0 otherwise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Distance to Union Station</strong></td>
<td>8,539</td>
<td>33,585</td>
<td>37,400</td>
<td>101,548</td>
</tr>
<tr>
<td>Network distance in metres from any station to Union Station</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.4 Econometric Modelling Framework

The first step in model development is the selection of an appropriate formulation. Regression models are the appropriate choice since both models considered in this research have continuous dependent variables. These types of models are often used to study transit trip generation and the residuals are assumed to have constant variance and follow a normal distribution. This research uses a version of these models that employ a Cobb-Douglas log-linear formulation as it ensures non-negativity of the response variable. This is a reasonable assumption since trip generation cannot be negative. The proposed Cobb-Douglas direct demand model is used to predict GO Transit rail ridership as a function of the logarithms of explanatory variables. Additional benefits of this type of modelling approach include simple interpretation of the elasticities of demand with respect to the independent variables; modelling non-linear effects; and similarity between the model and the Cobb-Douglas utility equation (Oum, 1989).

Two separate models are estimated in this study, namely trip production and trip attraction models. Each model identifies different factors that influence each trip activity. Trip production refers to rail trips that originated at the home location and trip attraction refers to rail trips destined for the work location (or any other location that is not the home location). The formulation of the Cobb-Douglas model is as follows:

\[
\ln(D_t) = \beta_o + \sum \beta_i \ln(x_i) + \sum \gamma_j y_j
\]

\(D_t\) is the dependent variable and refers to the total number of production/attraction trips by walk access/egress. \(\beta_o\) is the intercept, \(\beta_i\) refers to the vector of coefficients corresponding to the continuous variable set \(x_i\), and \(\gamma_j\) refers to the vector of coefficients corresponding to the dummy variable set \(y_j\).

The next step in model development includes the selection of independent variables for the purpose of analyzing their significance on the models. This selection process is informed by the reviewed literature in addition to our \textit{a-priori} hypotheses regarding the factors that influence TOD ridership via walk access/egress. However other factors which may affect TOD ridership,
such as car ownership, are not included in the developed models because the data are not available.

7.5 Empirical Investigation

A summary of the developed models is presented in Tables 7.2 and 7.3. A backward elimination process is used to develop the final model specifications. The first iteration of models includes all selected independent variables. Subsequently, variables are tested and those that are insignificant are removed. The final models include those variables that are statistically significant and contributed to an improvement of the R-squared statistic. Some of the variables that are considered but not included due to insignificance are the availability of bicycle parking and average household size. The 95 percent confidence limit for one-tailed tests (critical t-statistics value of 1.64) is used to identify the estimated parameters’ statistical significance. One-tailed tests are performed in accordance with the a-priori understanding and intuition regarding the effects of the variables (whether positive or negative) on ridership. All variables in the final models have intuitive signs. Variables used in the models are tested for co-linearity, and variables showing high co-linearity with other variables are removed from the final specification of the models.

7.5.1 Trip Production Model

The trip production model predicts GO Transit rail ridership specifically with walk as the only station access mode. Accordingly, it does not consider GO Transit rail trips where the access mode was anything other than walking from home to the rail station. Studying these specific trips identifies those factors that directly influence the choice to walk to the rail station. The identified factors are also attributes of TOD and therefore allow us to draw conclusions about the attributes of TOD and their ability to influence rail ridership with walk access.

The final specification of the trip production model consists of attributes of the built environment surrounding rail stations as well as station-level attributes. The adjusted-R squared statistic for the trip production model, as a measure of goodness-of-fit, is 0.56. Accordingly, the model explains 56 percent of the variation in the observed behaviour.
Table 7.2: Trip production model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>t-stats</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-10.72546</td>
<td>-5.601</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>log Population Density</td>
<td>1.06152</td>
<td>4.716</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>log AM Frequency</td>
<td>1.45374</td>
<td>5.045</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>log AM Arrivals</td>
<td>-0.05893</td>
<td>-1.869</td>
<td>0.067</td>
</tr>
<tr>
<td>log Walk Score</td>
<td>0.59345</td>
<td>1.74</td>
<td>0.088</td>
</tr>
<tr>
<td>log Parking Utilization</td>
<td>0.07756</td>
<td>2.247</td>
<td>0.029</td>
</tr>
<tr>
<td>Multiple R-squared:</td>
<td>0.6061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>0.565</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.3: Trip attraction model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>t-stats</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.67721</td>
<td>-0.788</td>
<td>0.436</td>
</tr>
<tr>
<td>log Employment Density</td>
<td>0.29884</td>
<td>1.813</td>
<td>0.079</td>
</tr>
<tr>
<td>log AM Frequency</td>
<td>1.36492</td>
<td>4.158</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Toronto Station</td>
<td>1.61135</td>
<td>4.892</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>log Distance to Union Station</td>
<td>-0.15897</td>
<td>-2.379</td>
<td>0.024</td>
</tr>
<tr>
<td>Multiple R-squared:</td>
<td>0.8131</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>0.789</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The variable *Population Density* represents the total number of people residing within an 800-metre radius of a GO Transit rail station and is a proxy for the amount of residential development in its surrounding area. The estimated coefficient for the logarithm of *Population Density* is statistically significant and has a positive parameter value. This finding suggests that greater residential density within a walking distance to rail stations is associated with higher rail ridership with walk access.

The variable *Walk Score* is determined for the 800-metre radius around GO Transit rail stations (Get Your Walk Score, 2015) and is a proxy for street connectivity that generally reflects the walkability of the surrounding neighbourhood of each rail station. Higher walk scores indicate that neighbourhoods are more walkable and have residents in closer proximity to transit and activity opportunities (e.g. commercial, recreational, etc.). The logarithm of the *Walk Score* has a positive value, indicating a positive association between the walkability and street connectivity within the built environment surrounding the stations and rail ridership with walk access.

A station-level attribute used in the model is *AM Frequency*. This attribute is defined as the morning frequency of GO Transit trains and is considered to be a primary indicator of the quality of rail service. The results indicate a positive coefficient for the natural logarithm of *AM Frequency* which suggests that higher train frequency, or better rail service, has a positive association with higher rail ridership with walk access to the rail station.

Another station-level attribute used in the model specification is *AM Arrivals*. This is the number of morning local transit feeder buses servicing a GO Transit rail station. Using this variable allows us to test the influence of a competing access mode (i.e. local bus access) on GO Transit rail ridership with walk access. The negative coefficient of the logarithm of *AM Arrivals* indicates that better accessibility to a rail station via local feeder buses is perceived as a more attractive option than walk access.

The station-level attribute *Parking Utilization* represents the percentage of parking spaces that are occupied in the morning peak period at a GO Transit rail station. The coefficient of the logarithm of this variable has a positive value indicating a positive association with the walk access mode. This result indicates that higher *Parking Utilization*, which accordingly yields
reduced parking availability, creates a disincentive for accessing the rail station by automobiles. Therefore, walk access for those living within walking distance of stations becomes a more attractive option when Parking Utilization is high. This is consistent with several studies noted in existing literature (Nelson et al., 2001; Cervero and Arrington, 2008), which identify station area parking as an important factor in TOD.

7.5.2 Trip Attraction Model

The trip attraction model predicts GO Transit rail ridership specifically with walk as the station egress mode. As such, it does not consider GO Transit rail trips where the egress mode was anything other than walking from the station to the final destination. The adjusted R-squared value for the trip attraction model is 0.79, indicating a relatively high goodness-of-fit of the model to the observed dataset.

A significant variable in the trip attraction model is Employment Density within the 800-metre radius of a GO Transit rail station. The positive coefficient for the logarithm of Employment Density suggests that a higher concentration of employment opportunities in the area surrounding a rail station has a positive influence on the number of rail trips terminating at that station, which are then followed by walk egress to the final destination. This variable is important since TOD policies encourage a high concentration of employment and commercial uses in the immediate area surrounding a transit station. The above-noted finding highlights that high employment density, which is a characteristic of TOD, can positively influence the number of rail trips which ultimately end with walking to the final destination.

The variable Distance to Union Station represents the network distance from each GO Transit rail station to Union Station. Union Station is Canada’s busiest intercity rail hub and the focal point for transit trips destined to Toronto’s CBD. Furthermore, all GO Transit rail lines terminate at Union Station. In Toronto, employment density is highly concentrated in the downtown core surrounding Union Station. As a result, Union Station is predominantly an egress point for many work trips. The estimated negative coefficient for the logarithm of Distance to Union Station suggests that as the distance to Union Station increases, rail ridership with walk egress declines. This is perhaps due to the built environment surrounding stations located farther away from Union Station, which are more likely to be suburban and low-density.
The dummy variable *Toronto Station* takes a value of one if the GO Transit rail station is located within Toronto, or 0 if otherwise. The estimated positive coefficient for this variable suggests that stations located in Toronto are more likely than stations outside Toronto to increase trip attraction with walk egress to commuters’ final destinations. Since Toronto has a higher concentration of jobs than its suburban counterparts, a higher number of work trips by rail are also likely to be destined to stations in Toronto.

The *AM Frequency* variable is statistically significant and has a positive association with trip attraction of with walk egress. Similar to the trip production model, this result suggests that higher train frequencies at the rail station will induce a greater number of trips that ultimately terminate with walking from the rail station to the final destination. Based on this result, any proposed improvements to train frequency may have the potential to increase the number of people using the GO Transit rail service including those walking to their final destination.

Variables used in the trip production model but dropped from the trip attraction model include *Parking Utilization*. This variable is not significant for the trip attraction model as parking availability at the egress station is inconsequential once a trip has been taken by rail. The use of a private automobile as an access mode at the start of the journey can certainly be influenced by the availability of parking at the starting GO Transit rail station. However, once the trip is made by rail, the private automobile is no longer available at the egress station, and hence trip attraction is unaffected by parking availability at the egress station.

### 7.5.3 Comparison of Elasticity Values

In the Cobb-Douglas formulation used in this research, the elasticities of the independent variables are simply the estimated parameters. For instance, the elasticity is determined as follows:

$$Elasticity\ of\ x_i = \beta_i$$

Elasticity measures how responsive the demand is with respect to changes in the explanatory variables. If the elasticity of demand is between 0 and 1, the demand is considered inelastic. An elasticity greater than one signifies demand is elastic. The estimated parameters in the trip production model indicate that demand is elastic with respect to the variables *Population Density*
and AM Frequency. Conversely, trip production is inelastic with respect AM Arrivals and Parking Utilization. The estimated parameters in the trip attraction model indicate that demand is elastic with respect to AM Frequency and inelastic with respect to Employment Density and Distance to Union Station. AM Frequency is elastic for both trip production and trip attraction which indicates that it is especially important since it influences rail trips for both walk access and egress modes.

Chan and Miranda-Moreno’s (2013) trip production model reports an elasticity of +0.74 percent increase in transit ridership for a one percent increase in the population surrounding transit stations. Their study considers all rail trips originating within a walking catchment area of only 500 metres. The trip production model in our research indicates a higher elasticity of +1.06 percent for the variable Population Density. However, an important distinction between the studies is that our research focusses only on rail trips that included walk as the access/egress mode and considers a larger catchment area of 800 metres. It follows that the elasticity of the demand for trips solely consisting of walk access/egress is slightly higher than the elasticity for all rail trips regardless of the access mode, as reported by Chan and Miranda-Moreno (2013).

7.6 Policy Implications

This research identifies station-level characteristics and built environment attributes that have statistically significant relationships with rail ridership by walk access/egress. There are several policy implications that may be derived from the modelling results, which are generally relevant for the design and implementation of TODs. Some of these policy implications are especially important for Metrolinx and its GO Transit rail network.

This research finds that higher residential density and greater walkability around the GO Transit rail stations have positive impacts on rail ridership with walk access. A policy implication derived from these results gives credence to the need for integrated land-use and transportation planning. Transportation policies aimed at increasing the use of active transportation (i.e. walking) for access modes must rely on land-use policies that stipulate development of higher residential density in the 800-metre radius of a rail station. In addition to density requirements, land-use policies which guide the design of the built environment, namely street patterns,
sidewalks, and boulevards, to improve pedestrian friendliness are also important. Since Metrolinx does not have the ability to mandate higher residential densities surrounding its rail stations, it is imperative that Metrolinx (like all transit authorities) be a stakeholder in establishing local municipal development standards that mandate higher residential densities where needed and to ensure optimal pedestrian connections to the rail station. Similarly, this policy implication can also be derived from the study finding which indicates that high employment density within an 800-metre radius of a rail station has a positive impact on rail ridership with walk egress. Accordingly, transit authorities such as Metrolinx should also be involved in establishing high employment densities around rail stations, especially for stations that predominantly serve as egress points for the journey to work.

This research also finds that the number of bus arrivals to the GO Transit rail station has a negative impact on rail ridership with walk access. Although rail ridership via bus access is also desirable for the purpose of reducing automobile usage, it is prudent to avoid creating competition with walk access. A policy implication related to TOD design and implementation is to limit the number of bus stops within the TOD 800-metre walking catchment area in order to avoid competition between the two access modes. From a Metrolinx policy perspective, it is more desirable to increase rail ridership with walk access than access by local buses. Although GO Transit rail stations have integrated facilities for local bus access, it is important to not prioritize this access mode for residents within the TOD walking catchment area as it can deter the use of active transportation modes for accessing the rail station.

The trip production and attraction modelling results indicate that the frequency of trains at rail stations has a positive association with the number of rail trips with both walk access and egress. An ongoing Metrolinx strategy is the Rapid Express Rail (RER) initiative, which proposes to make significant improvements to train frequencies, whereby trains will be running every 15 minutes or better, all day and in both directions (Metrolinx, 2017b). The above-noted modelling result reinforces one of the objectives of the RER initiative, in that it will likely increase rail ridership with walk access and egress.

Finally, the trip production modelling results indicate that higher parking utilization has a positive association with rail ridership with walk access. Although park-and-ride is a highly used
access mode for many GO Transit stations, the above result indicates that parking facilities at capacity create an incentive to walk to the rail station. Accordingly, a policy implication derived from this result is that Metrolinx should not prioritize expanding parking facilities if their main objective is to improve walk access for residents in the TOD walk catchment area.

7.7 Chapter Summary

This chapter examined the impacts of station level and built environment attributes on rail ridership with walk access and egress. Many of these attributes are characteristics of TOD and therefore allow us to draw inferences about the factors that encourage or deter walking to and from the central transit station of a TOD. A log-linear Cobb Douglas formulation was used to develop models for rail trip production and trip attraction. The research specifically focused on a study area of 800 metres surrounding GO Transit stations in the GTHA. Several important policy implications are derived from the results, including limiting access mode competition between local buses and walking within the TOD walking catchment area.

This chapter examined the influence of a specific land-use arrangement (TOD) on one aspect of the transportation system (station walk access/egress). Studying this interaction in the context of TOD is relevant since TOD is considered one ideal outcome of integrated land-use and transportation planning. Although there is extensive literature on TOD, there is a notable gap in empirical analyses. By using empirical models, this research identifies specific factors that influence or deter walking within a TOD catchment area. However, the models developed are aggregate in nature and may not be able to capture certain specific factors that influence individual behaviours with respect to access mode choice in the context of TOD. Understanding these specific behaviours requires disaggregate discrete choice models which require disaggregate data. As such, the next chapter develops a survey designed to gather data on individuals’ decisions in various hypothetical TOD contexts. This data is then used to develop discrete choice models which add to the results drawn in the preceding study.
CHAPTER 8

8 Mode Choices of Commuters Living near Regional Commuter Train Stations in the GTHA

8.1 Chapter Overview

The second step of phase three of this research is presented in this chapter. Phase three focuses on the context of TOD. The second step presents a survey design to collect disaggregate data on commuting mode choices in hypothetical scenarios of varying TOD attributes, including station level and built environment attributes. The second step also presents a discrete choice model using the survey data to explore the specific variables that influence commuting mode choice behaviour. This chapter is organized into the following sections: Section 8.2 introduces the motivation for this study. Section 8.3 provides an overview of the study area, survey design, and descriptive analyses of the collected data. Section 8.4 outlines the econometric modelling framework, and Section 8.5 presents the modelling results. Section 8.6 discusses the policy implications arising from the results. A summary of the chapter is presented in Section 8.7.

8.2 Introduction

As discussed in Chapter seven, TOD is an outcome of integrated land-use and transportation planning. TOD seeks to achieve compact, mixed-use, pedestrian and cyclist friendly urban development that is oriented towards the greater use of public transit. The urban commuter rail system is designed and operated to achieve a similar objective by reducing dependency on the private car for commuting. However, traditionally, park-and-ride has become the most common way of accessing commuter rail services. This does not fully align with the objectives of TOD nor the Metrolinx objective to increase active transportation access modes especially for residents in the walking catchment area of GO Transit stations. Thus, a better understanding of commuters’ mode choice preferences is warranted, especially in terms of the travel mode to access the commuter rail stations. Travel survey data that collects information on current mode choices (i.e. revealed preference) may not always reveal behaviours involved in commuter mode
choices as the existing patterns of accessing the commuter rail station is primarily park-and-ride. Therefore, this step of the research develops the Living Near Transit survey which is a joint revealed preference (RP) and stated preference (SP) survey that collects disaggregate data for empirical investigation.

The Living Near Transit survey collects SP data of workers’ commuting mode choices who reside near the rail stations of the regional transit network in the GTHA, namely the GO Transit network. In particular, this study examines various factors that influence respondents’ mode choices in the context of varying TOD attributes. Amongst these factors are certain characteristics of TOD which may encourage or hinder the use of various modes to access the GO Transit stations. The findings of this research shed light on important policy considerations, especially concerning the use of active transportation modes to access GO Transit stations centered in TODs.

This step of the research includes the development and execution of the Living Near Transit survey, which adopts a hybrid RP-SP approach to probe the travel behaviour of respondents under hypothetical scenarios of TODs. The SP responses are pivoted on respondents’ current travel and household attributes, as reported in the first (RP) part of the survey. This unique approach renders models that are sensitive to TOD characteristics that may not currently exist in transit station areas in the GTHA. A detailed descriptive analysis of the collected data is provided to examine the factors that may influence certain mode choices. The collected data is then used for the estimation of a random parameters logit model that considers eight commuting mode choice alternatives. These commuting mode choice alternatives include primary modes as well as access modes to the GO Transit station. The modelling results have implications on policies and guidelines for the design and implementation of TOD.

8.3 Study Area, Survey Design and Descriptive Analyses

8.3.1 Study Area

The study area of this step of the research is the GTHA, which is also the study area of research set out in the previous chapter. Therefore, initial details of the study area are provided in section 7.3.1. It is also relevant to note that public transportation infrastructure throughout the GTHA is
severely lacking considering its physical size and population. The quality of the regional public transportation network is an important consideration as cross-regional commuting is common (one in four trips in the GTHA), however, the network lacks sufficient integration to effectively serve this travel demand. The GTHA is serviced by one regional transit agency and several independently governed local transit agencies. Metrolinx is the regional transportation authority and GO Transit is the division of Metrolinx that operates the regional public transit service. The GO Transit service is an extensive network of train lines and bus routes that carries 65 million passengers annually between various stations throughout the GTHA and the central station in the City of Toronto (Union Station).

The GO Transit network consists of 64 rail stations which form the basis of the target survey locations for this research. The target survey locations are comprised of an area defined by a 1000 metre radius surrounding each station, as set out in Figure 8.1. The previous chapter used a walking catchment area of 800 metres, which is considered a standard in existing research on TOD. However, in this step of the research, the target survey area is expanded by 25 percent to a 1000 metre in order to increase the response rate of the survey.

![Figure 8.1: Target Survey Location](image)

*not to scale*
8.3.2 Survey Design

The Living Near Transit survey is a web-based, hybrid RP-SP survey of commuter behaviour under hypothetical scenarios of TOD attributes, which pivots the responses of survey participants on their current home and work locations. The survey collects information on respondents’ current work trips, commuting mode choices, and household characteristics. As set out in Figure 8.2, the Living Near Transit survey consists of four parts. Part A poses two important questions to respondents which act as the qualifier for participation in the survey. Part B collects RP data, such as respondents’ current home and work locations, vehicles per household and workers per household. Part C collects SP data by presenting six hypothetical scenarios of varying attributes of TOD and mode choice alternatives. Part C uses the respondents’ home and work locations reported in Part B to establish the baseline time and costs associated with various mode choice alternatives presented in the six SP scenarios. Finally, Part D collects further socioeconomic and demographic information pertaining to the households, such as age, gender and household income.
Figure 8.2: Data Model for Living Near Transit Survey
8.3.2.1 Survey Part A

Prior to collecting the above described RP and SP data, respondents must qualify to participate in the survey. The qualifier is whether respondents reside within 1,000 metres of a GO Transit station and secondly whether they work outside of the home. These qualifiers are necessary as the focus of this survey is specifically to examine commuting choice behaviour of individuals who work outside the home and reside within the walking catchment area of a transit station. An excerpt of the survey depicting Part A is shown in Figure 8.3.

![Survey Part A Qualification Questions](image)

Figure 8.3: Part A of the Living Near Transit Survey

8.3.2.2 Survey Part B

Part B of the survey collects RP data regarding respondents’ current commute trips, retrospective mode choice and mobility tool ownership and other sociodemographic information. Respondents are also required to indicate specific locational information, including their current home and work locations, as well as their closest GO Transit station. This information is used to provide locational context to the SP data collected in Part C. The collection of this information is essential for the SP component as the scenarios posed to the respondents include attributes, such as travel time and cost, which are pivoted on the home and work locations reported in this part of the survey. Although the levels of attributes vary across the SP scenarios, the baseline time and cost variables associated with the various modes are determined using the information collected in this part of the survey. Figure 8.4 is an excerpt from Part B of the survey.
Figure 8.4: Excerpt of Part B of the Living Near Transit Survey
8.3.2.3 Survey Part C

Part C of the survey captures individual-level mode choice behaviour for both the main and access modes of work trips. The main mode is defined as the mode which is used for the longest duration of time during the work trip. The access mode is defined as the mode used to access the GO Transit station for those individuals whose main mode is GO Transit rail. The RP data collected in Part B of the survey is used to develop six hypothetical scenarios of travel mode choices in terms of the main mode (private car, GO transit, local transit) and if GO Transit is a feasible alternative, the access mode to the area’s GO Transit station. There are two types of attributes used in the hypothetical scenarios: 1) surrounding environment characteristics, and 2) station level attributes. It is important for this research to capture the characteristics of the environment as these may influence respondents’ access mode choices. Existing research on TOD established that the physical environment surrounding a transit hub is a factor which impacts individuals’ choices to use public transportation. For instance, an attribute such as bus stop density, which reflects the proximity of a bus stop to the home location, is an indicator of transit accessibility that may influence the respondents’ access mode choice. Station-level attributes are also important to capture in this research, as they encourage or deter respondents from using certain access modes. For instance, commuters would likely consider availability and cost for parking at the station when deciding whether or not to use the park-and-ride access mode.

The scenarios in the SP component include customized attributes that are based on the current commute characteristics collected in Part B. Table 8.1 represents the generic template used to generate the attribute levels for all six SP scenarios. The variables are divided by cost, time and TOD factors. Some variables have one level, denoted as “current”, which use the baseline value of that variable corresponding to the data collected in Part B of the survey. Other variables have multiple levels which can vary across the six scenarios. These levels, which add or subtract from the baseline value in a systematic way, are determined using efficient design. The values assigned to multiple level attributes are defined in Table 8.2. For example, there are three levels of parking cost at the GO Transit station, which are defined as low ($0), medium ($4) and high ($8). The six scenarios can have any one of these three levels. Other variables such as travel cost...
do not have multiple levels and are therefore consistent throughout the scenarios as the “current” travel cost.
Table 8.1: Template of Stated Preference Scenario Attributes

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Travel Cost ($)</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td><em>Includes parking cost at destination</em></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Additional Parking Cost at Access GO station ($) Not applicable for car pool Option</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>3 levels</td>
<td>-</td>
<td>-</td>
<td>--</td>
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</tr>
<tr>
<td>Additional Local Transit-GO Transit Access Fare ($) Cost of local transit fare used to access GO station</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>Current</td>
<td>--</td>
<td>Current</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Walk Time (minutes)</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td><em>Once you have reached the grounds of the GO station, what is the time it takes you to walk to your platform</em></td>
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<td></td>
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<tr>
<td>Wait time (minutes)</td>
<td>--</td>
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<td>-</td>
<td>3 levels</td>
<td>3 levels</td>
<td>3 levels</td>
<td>3 levels</td>
<td>3 levels</td>
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<tr>
<td><em>The time you wait on the platform for your train to arrive</em></td>
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<tr>
<td>Access Time (minutes)</td>
<td>--</td>
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<td>-</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
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<td>Current</td>
</tr>
<tr>
<td><em>The time it takes you to reach the GO station from your home</em></td>
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<tr>
<td>In-vehicle travel time(minutes)</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
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<tr>
<td>mode of travel to reach your destination</td>
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<td></td>
</tr>
<tr>
<td>Egress Time (minutes)</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td></td>
</tr>
<tr>
<td>The time it takes to travel from</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>the egress GO station to your</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>destination</td>
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<tr>
<td>TOD FACTORS</td>
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<tr>
<td>Availability of Bicycle</td>
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<tr>
<td>Parking at GO station</td>
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<tr>
<td>Distance from your home</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>3 levels</td>
<td>3 levels</td>
<td>3 levels</td>
<td>3 levels</td>
<td></td>
</tr>
<tr>
<td>location to the bus stop nearest</td>
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<tr>
<td>your home (metres)</td>
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<tr>
<td>The time between buses at the</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>3 levels</td>
<td>3 levels</td>
<td>3 levels</td>
<td>3 levels</td>
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</tr>
<tr>
<td>bus stop nearest your home (minutes)</td>
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<tr>
<td>How frequently buses depart the bus</td>
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<td>stop</td>
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</tr>
<tr>
<td>YOUR CHOICE: You may choose only one</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
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<td>○</td>
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<tr>
<td>Mode Attribute</td>
<td># of Levels</td>
<td>Attribute Levels</td>
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<td></td>
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<tr>
<td>Total Travel Cost ($) (Includes Parking Cost at Destination)</td>
<td>NA</td>
<td>Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking Cost at GO station ($) (not applicable for Car Pool Option)</td>
<td>3</td>
<td>Low - (Current) 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Medium – (Guaranteed parking but does not guarantee location) 4</td>
<td></td>
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<td></td>
<td></td>
<td>High – (Reserved parking location) 8</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Local Transit-GO Transit Access Fare ($)</td>
<td>NA</td>
<td>Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk Time (minutes) (between Local &amp; Regional Transit)</td>
<td>NA</td>
<td>Current</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Wait Time (minutes)</td>
<td>3</td>
<td>Low -50%</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>Medium Current</td>
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<tr>
<td></td>
<td></td>
<td>High +50%</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Access Time (minutes)</td>
<td>NA</td>
<td>Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-vehicle Travel Time (minutes)</td>
<td>NA</td>
<td>Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egress Time (minutes)</td>
<td>NA</td>
<td>Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of Bicycle Parking at GO station</td>
<td>2</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from home to nearest bus stop (metres)</td>
<td>2</td>
<td>Medium 0 - 200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>High 201 - 400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average time between bus arrivals at local bus stop (minutes)</td>
<td>2</td>
<td>Low 0 - 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>High 11 - 20</td>
<td></td>
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</tr>
</tbody>
</table>
8.3.2.4 Survey Part D

Additional socioeconomic and demographic information is collected in Part D of the survey, including the participant’s gender, employment status, and income characteristics. These characteristics provide insight into the respondent’s household responsibilities, out-of-home time commitments, and budget flexibility, all of which can influence travel mode choice and, if using GO Transit, the access mode choice. The purpose of splitting the collection of sociodemographic information between Parts A and D of the survey is to allow participants to more quickly advance to the most critical part of the survey in Part C and to avoid respondent drop out prior to collection of the stated preference information. An excerpt of Part D is provided in Figure 8.5.

![Figure 8.5: Excerpt of Part D of the Living Near Transit Survey](image-url)

8.3.3 Descriptive Analysis

8.3.3.1 Data Collection

The Living Near Transit survey incorporates actual level-of-service attributes of alternative modes for each respondent. The distribution and programming of the survey are conducted by a market research firm R.A. Malatest and Associates Limited in conjunction with the author of this research. Two methods are employed to recruit respondents: invitations with a link to the survey are mailed out, and digital invitations with a link to the survey are emailed to individuals in a panel maintained by GO Transit. The survey invitations are sent in accordance with a stratified
sampling approach, whereby GO Transit rail stations are grouped into strata based on two specific characteristics, namely residential density and the potential for transit-oriented development in the stations’ surrounding walking catchment areas. Following this, mail outs are allocated to each stratum of GO Transit rail stations based on the proportion of households in that particular stratum relative to the total number of households for all stations. This type of sampling strategy makes use of prior information to subdivide the population into strata such that the units within each stratum are as homogenous as possible with respect to a stratifying attribute (Richardson et al, 1995). Moser and Kalton (1979) demonstrate that stratified sampling methods can reduce sampling errors significantly.

As part of the first round of survey distribution, approximately 15,000 invitations are sent out. Of these, there are 834 survey attempts and only 219 respondents who lived within a 1-kilometre radius of a GO Transit rail station and thus eligible to complete the stated preference component of the survey. The final sample of full survey completions by respondents within the 1-kilometre catchment is 139. However, each complete survey response yields six survey records corresponding to each of the six presented SP scenarios. Therefore, a total of 834 records are included in the final dataset used for the descriptive analysis and modelling.

8.3.3.2 Descriptive Statistics Overview

The respondents of this sample are fairly evenly split in terms of gender, with 52 percent male and 48 percent female respondents. Gender can be an important demographic characteristic to consider as certain household responsibilities associated with traditional gender roles may influence travel behaviour, as is indicated in existing literature.

Another notable demographic characteristic of the respondents includes the number of workers per household. Approximately 70 percent of respondents are part of households with at least two workers. Comparatively, the 2006 Transportation Tomorrow Survey, reveals that around 28 percent of households in the GTHA are two-worker households (DMG, 2013). The proportion of the respondents who belong to two-worker households is significantly higher than the average percentage of two-worker households across the GTHA. Although respondents are required to be employed in order to participate in the survey, the percentage of respondents belonging to two-worker households is high, and perhaps suggests that there is a higher concentration of two-
worker households that live in close proximity to this higher order transit. This may be an intuitive finding considering that two-worker households often make commuting trade-offs between individual workers (as illustrated in Chapter five of this research). The availability of transit is a factor that may allow these households to make such trade-offs.

The various stations within the GO Transit rail system are largely located in suburban areas, which may influence the types of households located within the walking catchment area of GO Transit stations. Often associated with the number of workers per household is the number of cars per household. Unsurprisingly, the survey data shows that only seven percent of the households do not own any vehicles. Dependence on the automobile is a common characteristic of suburban households and one which TOD policies work towards reducing. Interestingly, although there is a high proportion of two-worker households, there is generally an even split between households with one and two vehicles – 43 percent and 41 percent, respectively. It can then be inferred that some two-worker households may be relying on only one car and thus using other modes for at least one of the work trips. The mode split of respondents is, therefore, an important aspect of the survey results to consider. The most popular mode choice of the respondents (25 percent) is the automobile as the main travel mode. This is a somewhat predictable statistic provided that auto-dependence is a common characteristic of suburban dwellers. However, the second most popular mode choice is GO Transit with walk access (20 percent). This is also the most popular access mode choice amongst all the GO Transit main mode options. This statistic reveals that walking to the GO Transit station is a viable commuting option in certain scenarios. This research explores those scenarios to understand which factors contribute to the popularity of that main and access mode choice.

Another important mobility tool is having possession of a transit pass, which may be an important attribute for explaining the access mode choices of residents who live in the walking catchment area of GO Transit rail stations. 58 percent of respondents own a transit pass specifically for GO Transit. Other important attributes to consider are the housing type and tenure which are indications of residents’ lifestyle preferences. 90 percent of the sample own their current homes and 61 percent live in detached homes. Detached homes in close proximity to GO Transit rail stations is a common characteristic of those stations located in Toronto’s suburban regional municipalities such as Durham, Peel, York, and Halton. High-density
dwellings such as townhomes and multi-unit structures that are in close proximity to stations are more common in Toronto.

8.3.3.3 Descriptive Analysis of Factors Influencing Access Mode Choice

This research examines certain demographic and locational characteristics of the respondents relative to their mode choices. Although there is a fairly even split between male and female respondents in the survey, that does not continue to be the case when reviewing gender relative to mode choices. As illustrated in Figure 8.6, when the statistics respecting gender are examined relative to the various mode choices, it is revealed that females comprise the larger proportion of respondents that choose GO Transit across all of the access mode options with the exception of bike access (modes 4 to 7). Another significant statistic related to gender is that males represent a larger proportion of those respondents that choose a main mode that involves an automobile, namely auto and carpool (modes 1 and 2).

Figure 8.6: Gender relative to mode choice

It was also previously reported that there is a large proportion of respondents who come from two-worker households. It now appears that those respondents have a strong preference for two mode choices in particular, both of which involve carpooling, as illustrated in Figure 8.7. Of
those who choose carpooling as the main mode, 93 percent are from two-worker households. Similarly, of those who choose carpooling as the access mode for the GO Transit main mode, 94 percent are from two-worker households. These results are interesting since it may be more likely that respondents carpool with another worker from their household. Across all choices, the mode with the lowest proportion of two-worker households is local transit as the main mode. This result may be tied to the cost of transportation and household income. One-worker households would likely have a lower household income than their two-worker household counterparts and therefore may be more inclined to choose a mode that is less costly (i.e. local transit).

Figure 8.7: Two-worker households relative to mode choice

The above inference is further supported when examining the percentage of households with two or more vehicles. Across all choices, the mode with the lowest proportion of households with two or more vehicles is local transit as the main mode, as illustrated in Figure 8.8. The majority of those who choose local transit (73 percent) come from households with zero or one vehicle. Multiple car ownership may be associated with higher incomes, therefore the choice to take local transit may again be associated with income. One statistic which is not intuitive and requires
further investigation is that across all the mode choices, the mode with the highest proportion of households with two or more vehicles is GO Transit with carpooling as the access mode.

![Graph showing mode choice percentages]

Figure 8.8: Households with two or more cars relative to mode choice

Finally, the locational characteristic of average distance to the GO Transit station is examined across all modes, as illustrated in Figure 8.9. The most significant statistic is that a vast majority of those who choose main modes or access modes involving the automobile (mode 1, mode 2, mode 4, and mode 5) live in the outermost part of the catchment area (751-1,000 m away from the GO Transit rail station). Nearly all (92 percent) of those who choose GO Transit with carpool access (mode 5) and nearly all (90 percent) of those who choose carpool as the main mode (mode 2) live in this outermost part of the catchment area. Furthermore, 76 percent of respondents choosing the auto main mode (mode 1) and 69 percent of respondents choosing the park-and-ride access mode (mode 4) also live in this area. The common characteristic of these statistics is the reliance on the automobile and greater distance from the GO Transit station. As the distance to access the GO Transit station increases, households tend to rely more on the automobile for transportation. Interestingly, there is significantly higher proportion of the above-described respondents who choose carpooling relative to individual auto usage. One possible explanation for this may the prevalence of two-worker households amongst residents of the catchment area, who have the ability to carpool with other workers in their household. As
previously stated 70 percent of respondents are part of two-worker households. Another significant statistic revealed in Figure 8.9 is that amongst the GO Transit modes, the access mode with the highest proportion of people in the closest area to the GO Transit station (less than 250 m) is bike access followed by walk access. This supports the previous inference that proximity plays a role in the access mode choice, even when considering the use active transportation for some part of the trip to work.

Figure 8.9: Average distance to GO Transit station relative to mode choice

8.4 Econometric Modelling Framework

This research applies a random parameters logit model, also known as a mixed logit model, to examine the mode choices of individuals living near GO Transit rail stations. This model accounts for the non-independence between observations of the same respondent in the Living Near Transit survey data. It considers the mean and standard deviation of the random parameter to identify sources of systematic preference heterogeneity. It is, therefore, an appropriate modelling technique for stated choice data (Greene et al., 2012).
In certain ways, the random parameters logit model is similar to the random parameters model for linear regression (Revelt and Train, 1998). Setting aside the error components, the probability of the random parameters logit model used in this research is derived from the mixed logit formulation presented by Greene et al. (2012):

\[
\text{Prob}(j|v_i) = \frac{\exp(\alpha_j + \theta'_j z_i + \Phi'_j f_{ji} + \beta'_j x_{ji})}{\sum_{q=1}^J \exp(\alpha_q + \theta'_q z_i + \Phi'_q f_{qi} + \beta'_q x_{qi})}
\]

where

\[
U(j, i) = \alpha_j + \theta'_j z_i + \Phi'_j f_{ji} + \beta'_j x_{ji},
\]

\(j = 1, \ldots, J_i\) alternatives in the choice set of individual \(i\);

\(\alpha_j\) is a fixed alternative specific constant which is nonrandom;

\(\theta_j\) is a vector of fixed coefficients which are nonrandom;

\(\Phi_j\) is a vector of fixed coefficients which are nonrandom;

\(\beta_{ji}\) is a coefficient that is randomly distributed across individuals;

\(z_i\) is a set of individual characteristics which do not vary across the choice alternatives such as gender;

\(f_{ji}\) is a vector of \(M\) individual and choice varying attributes of choice alternatives such as \textit{travel cost};

\(x_{ji}\) is an attribute that varies across individuals and choices.

The presented mixed model of mode choices in the context of TOD consists of eight specific alternative modes (denoted as \(j\)) for the journey to work. These alternatives consist of the main mode choice as well as the mode choice used to access the GO Transit station (herein referred to as “access mode choice”). These alternatives include:
1. Auto
2. Carpool
3. Local transit
4. GO Transit rail with park-and-ride access
5. GO Transit rail with carpool access
6. GO Transit rail with local transit access
7. GO Transit rail with walk access
8. GO Transit rail with bicycle access

The specification of the individual specific parameter vector $\beta_i$, as set out below, gives rise to the mixed model formulation.

$$\beta_{ki} = \beta_k + \sigma_k v_{ik},$$

and

$$\alpha_{ji} = \alpha_j + \sigma_j v_{ji},$$

where the population mean is $\beta_k$, the standard deviation of $\beta_{ki}$ around $\beta_k$ is $\sigma_k$, and the individual-specific heterogeneity is $v_{ik}$ with a mean of zero and standard deviation of one. The elements of $\beta_i$ and the alternative specific constants $\alpha_{ji}$ are randomly distributed across individuals with fixed means. This formulation is further refined to allow the means of the parameter distributions, $z_i$, to be heterogeneous with observed data ($z_i$ does not include one). This would be a set of choice invariant characteristics that produce individual heterogeneity in the means of the randomly distributed coefficients such that:

$$\beta_{ki} = \beta_k + \delta_k z_i + \sigma_k v_{ki},$$

In this research, individual heterogeneity is captured by the random parameter corresponding to in-vehicle travel time which is specified with a normal distribution.

### 8.5 Empirical Investigation

The presented specification is the final model selected by considering expected signs and t-statistics of the parameters. A 95 percent confidence level (critical t-statistic value of 1.64) is used
to investigate the statistical significance of the parameters. Based on a theoretical understanding and strong intuition regarding the factors affecting the models, one-tailed tests are performed. Certain variables with t-statistics lower than 1.64 are retained in the model given their importance in explaining behaviour. A backwards elimination process is used to determine the final model specification. Initially, several variables are considered for modelling; however, certain variables are left out of the model specification due to their lack of statistical significance or due to the lack of data resulting from respondents selecting the survey option of prefer not to say (i.e. many respondents do not report their incomes). Goodness-of-fit (rho-square values) of the estimated model is calculated. A higher rho-square value indicates a better fit of the estimated model with the observed data. The results of the final mixed logit model are presented in Table 8.3. The reference alternative in the model is the “auto” mode. The presented model is estimated using NLOGIT software.

The estimated mixed discrete choice model takes into consideration gender by using the dummy variable gender: male. The estimated parameter for this variable has a negative coefficient for the GO Transit modes with park-and-ride access and carpool access. This is an indication that males living within a walking catchment area of the GO Transit rail station are less likely than females to choose these GO Transit modes. This finding is in line with the descriptive analysis, which shows that despite a nearly even split between male and female respondents, the proportion of females is higher for most chosen GO Transit modes, including the above-noted access modes.

Another socio-demographic variable considered in the model is multiple workers in a household, which is a dummy variable that represents respondents who belong to households with at least two workers. The estimated parameter for this variable is statistically significant and positive for the carpool main mode and GO Transit with carpool access mode. Although this mode does not distinguish between intra- and inter-household carpooling, we can infer from the above result that multiple worker households carpool likely due to the fact that two work trips originate from one home location. This result is also in line with the descriptive analysis which shows a very high percentage of multiple worker households choosing the above-noted modes. As noted in the descriptive analysis, there is a much higher percentage of respondents from two-worker households relative to households across the GTHA, which is significant for the policy implications derived from the above result.
The variable *households with two or more vehicles* is a dummy variable which is statistically significant and has a negative coefficient for local transit main mode and a positive coefficient for the mode GO Transit with carpool access. These findings are in line with the descriptive analysis and suggest that higher auto-ownership results in a lower likelihood to choose local transit. However, interestingly there is a positive correlation between households with two or more vehicles and the above noted carpooling access mode, which suggests that carpooling is not a result of lack of vehicle availability. The final socio-demographic variable used in the model specification is *home ownership* which is a dummy variable that represents whether the respondent is a home owner. The estimated parameter value is negative for the carpool and local transit main modes. Since these two modes are often associated with cost savings and home ownership is often associated with higher incomes, it may be inferred that there is an economic reasoning for the above-noted modelling result. This result does not suggest that high-income households do not prefer GO Transit modes as indicated by the positive estimated parameter for *home ownership* with respect to the GO Transit mode with carpool access.

The model specification also includes attributes associated with TOD, such as the *distance to nearest GO station*. This variable represents the distance from the respondents’ home location to the nearest GO Transit rail station, following the road network. The estimated parameter is positive for the carpool main mode and GO Transit with carpool access mode. These results are in line with the descriptive analysis and suggest that individuals residing in the outermost region of the catchment area of the transit station are more inclined to use the automobile due to their proximity to the station. Also, as previously stated, many respondents are part of two-worker households and therefore may be inclined to carpool with workers from the same household. Conversely, the estimated parameter has a negative value for the GO Transit with bike access mode. This finding is intuitive since longer distances make it less likely for individuals to use an active transportation mode, such as biking, perhaps due to the physical and time-consuming nature this access mode demands.

The variable *parking cost at GO station* represents the parking cost at the GO Transit station for commuters who are either using the park-and-ride or carpooling access modes. The estimated negative parameter value for the GO Transit with park-and-ride mode indicates that parking costs discourage the use this mode, as it involves single occupancy vehicle usage. Conversely, the
The estimated positive parameter for the mode GO Transit with carpool access indicates that respondents may be motivated to carpool to reduce parking costs per person.

The variable *access time home to GO station* represents the commuting time to access the GO Transit rail station from respondents’ home locations using local busses. The negative parameter value is statistically significant for the mode GO Transit with local transit access, which is intuitive considering higher access times may deter respondents within a TOD walking catchment area from using this mode. Despite the preference for local transit over auto usage, this finding is not likely to influence the improvement of local transit within a TOD since active transportation modes are prioritized in TODs for accessing the transit station.

The variable *distance to nearest bus stop* represents the walking distance from the respondent’s home to the nearest local bus stop. The estimated coefficients have a negative parameter value for the GO Transit modes with carpool access and bike access. Although there is no obvious explanation, it is probable that a longer distance to the nearest bus stop is perceived as resulting in a longer access time to the GO Transit station irrespective of the access mode, thus explaining the negative parameter value relative to the auto main mode.

The variable *time between bus arrival at the nearest bus stop* is a proxy for the frequency of local buses within the TOD’s walking catchment area. This variable has an inverse relationship to frequency, meaning that higher average time between bus arrivals corresponds to lower bus frequency. Also, this variable is alternative specific, meaning that different coefficients are estimated for the different modes. The estimated coefficient has a positive value for the GO Transit modes with active transportation access modes (walk and bike), which suggests that higher average time between bus arrivals correlates to a higher likelihood of commuters choosing active transportation modes to access the GO Transit station. These results indicate that there is competition between the local transit access mode and the active transportation access modes.

The variable *in-vehicle travel time* represents the total travel time of the respondent’s journey to work while using the main mode (i.e. excluding wait time at the platform, access time to the GO Transit rail station, and egress time from the last GO Transit rail station to the final destination). The variable *in-vehicle travel time* is a generic variable meaning that the estimated parameter has the same value for all modes. This assumption is based on the theory that in-vehicle travel time
has the same effect on the utility of commuters irrespective of the mode they choose. A random parameter is estimated for this variable to capture systematic preference heterogeneity amongst individuals with respect to the effects of in-vehicle travel time on their mode choices. The mean of this parameter value has a negative value and is statistically significant, which suggests an inverse relationship between in-vehicle travel time and choosing any mode.
Table 8.3: Output of Main Mode and Access Mode Choice Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
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<td>Auto</td>
<td>0.525</td>
<td>4.62</td>
</tr>
<tr>
<td>Carpool</td>
<td>-3.490</td>
<td>-3.44</td>
</tr>
<tr>
<td>Local transit</td>
<td>1.148</td>
<td>2.82</td>
</tr>
<tr>
<td>GO Transit with park and ride access</td>
<td>-0.017</td>
<td>-0.06</td>
</tr>
<tr>
<td>Alternative specific constant (GO Transit with carpool access)</td>
<td>-6.558</td>
<td>-4.02</td>
</tr>
<tr>
<td>GO Transit with local transit access</td>
<td>0.301</td>
<td>1.58</td>
</tr>
<tr>
<td>GO Transit with walk access</td>
<td>0.964</td>
<td>3.14</td>
</tr>
<tr>
<td>GO Transit with bicycle access</td>
<td>0.417</td>
<td>0.88</td>
</tr>
<tr>
<td>In-vehicle Travel Time (all modes) Standard Deviation: 0.051</td>
<td>-0.015</td>
<td>-2.07</td>
</tr>
<tr>
<td>Gender: Male (GO Transit with park and ride access)</td>
<td>-0.396</td>
<td>-1.33</td>
</tr>
<tr>
<td>Gender: Male (GO Transit with carpool access)</td>
<td>-0.555</td>
<td>-1.49</td>
</tr>
<tr>
<td>Multiple workers in household (Carpool)</td>
<td>1.943</td>
<td>3.03</td>
</tr>
<tr>
<td>Multiple workers in household (GO Transit with carpool access)</td>
<td>2.172</td>
<td>2.94</td>
</tr>
<tr>
<td>Households with two or more vehicles (Local transit)</td>
<td>-2.557</td>
<td>-5.00</td>
</tr>
<tr>
<td>Households with two or more vehicles (GO transit with carpool access)</td>
<td>0.003</td>
<td>2.97</td>
</tr>
<tr>
<td>Home ownership (Carpool)</td>
<td>-0.126</td>
<td>-2.76</td>
</tr>
<tr>
<td>Home ownership (Local transit)</td>
<td>-0.152</td>
<td>-3.46</td>
</tr>
<tr>
<td>Home ownership (GO transit with carpool access)</td>
<td>1.777</td>
<td>1.73</td>
</tr>
<tr>
<td>Distance to nearest GO station (Carpool)</td>
<td>0.002</td>
<td>2.67</td>
</tr>
<tr>
<td>Distance to nearest GO station (GO transit with carpool access)</td>
<td>0.003</td>
<td>2.97</td>
</tr>
<tr>
<td>Distance to nearest GO station (GO transit with bike access)</td>
<td>-0.001</td>
<td>-2.46</td>
</tr>
<tr>
<td>Parking cost at GO station (GO transit with park and ride access)</td>
<td>-0.068</td>
<td>-1.52</td>
</tr>
<tr>
<td>Parking cost at GO station (GO transit with carpool access)</td>
<td>0.069</td>
<td>1.27</td>
</tr>
<tr>
<td>Access time home to GO station (GO transit with local transit access)</td>
<td>-0.028</td>
<td>-3.38</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Distance home to nearest bus stop (GO transit with carpool access)</td>
<td>-0.002</td>
<td>-1.13</td>
</tr>
<tr>
<td>Distance home to nearest bus stop (GO transit with bike access)</td>
<td>-0.002</td>
<td>-1.42</td>
</tr>
<tr>
<td>Time between bus arrival at nearest bus stop (GO Transit with walk access)</td>
<td>0.024</td>
<td>1.33</td>
</tr>
<tr>
<td>Time between bus arrival at nearest bus stop (GO Transit with bike access)</td>
<td>0.052</td>
<td>1.65</td>
</tr>
</tbody>
</table>

**Rho-squared**

0.17

### 8.6 Policy Implications

The empirical investigation presented in the preceding section identifies demographic factors, travel attributes, and TOD characteristics that influence mode choice behaviour of residents in the walking catchment area of a GO Transit rail station. There are several policy implications that may be derived from the modelling results which are applicable to TODs in general and more specifically to the areas surrounding GO Transit rail stations.

Of the demographic factors considered, the research finds that residents from two-worker households are likely to choose carpool as both the main mode and the GO Transit access mode over single occupancy auto usage. As such, if the desired effect is to increase carpooling within a TOD catchment area thereby reducing the total count of vehicle usage, carpool designated parking spots should be implemented and prioritized at all GO Transit stations. Since there may be a high proportion of two-worker households in the walking catchment area of GO Transit rail stations, there is greater opportunity to motivate residents to carpool to the GO Transit station, which would help achieve a general TOD objective to reduce overall auto usage by reducing single occupancy auto usage.

Of the TOD characteristics considered, this research finds that residents located further from the GO Transit rail stations are likely to choose the carpooling main mode and the GO Transit mode with carpool access. This result reinforces the previously noted policy implication that designated carpool parking spots should be prioritized to achieve a reduction in overall auto usage. In addition to the above-described motivation for two-worker households, this policy may
also motivate residents living in the outer region of the catchment area to use carpooling for accessing the GO Transit rail station. This research also finds that residents located further from the GO Transit rail station are less likely to choose bike as the access mode for GO Transit rail. A TOD related policy implication from this finding is to concentrate residential land-use near the GO Transit rail stations as residents in these areas would be more likely to choose an active transportation mode. Prioritization of residential uses near the rail station may also be achieved through the provision of quality cycling infrastructure on the road network near the GO Transit rail station. Although Metrolinx does not control the development patterns of the lands surrounding its GO Transit rail stations nor the provision of infrastructure, it would be prudent for Metrolinx to be a stakeholder in the establishment of local by-laws and urban design guidelines by the governing municipalities.

This research considers attributes of the choice alternatives and finds that parking cost at the GO Transit rail station deters residents from choosing park-and-ride access and encourages the carpooling access mode to the GO Transit rail station. These results perhaps suggest that residents will choose carpool access as a measure to reduce the cost of parking per person. In addition to the previously noted policy implications that encourage carpooling, these results suggest that implementing a certain level of paid parking may also encourage carpooling access and deter park-and-ride access to the GO Transit rail station. This may also help achieve the overall TOD objective of reducing auto usage. However, caution should be taken when implementing any level of paid parking as this may deter the use of GO Transit as park-and-ride is a highly used access mode for GO Transit stations, especially in Toronto’s suburbs.

Another finding from the modelling results is that lower bus frequency within the walking catchment area encourages residents to choose active transportation modes such as walking and biking for accessing the GO Transit rail station. Despite the preference for local transit over auto usage, it is important not to create further competition by improving the frequency of local buses within the walking catchment area of a TOD. Such improvements may deter residents from choosing active transportation modes to access the central transit station, which Metrolinx identifies as an important consideration for residents within GO Transit rail station catchment areas. Metrolinx should coordinate with local transit providers to control the frequency of local buses stopping in areas within the walking catchment area of a GO Transit rail station.
8.7 Chapter Summary

This chapter presented a study of commuting mode choice behaviour of individuals residing within a one-kilometre radius of GO Transit rail stations. The access modes to the GO Transit rail stations were of particular importance since a key objective of Metrolinx is to encourage active transportation access modes. First, the chapter presented the Living Near Transit survey which was designed to collect disaggregate stated preference data on the commuting mode choices of residents in the walking catchment area of GO Transit rail stations. Second, a descriptive analysis and empirical investigation of the collected data revealed insights about demographic factors, mode attributes and TOD characteristics that influence mode choice behaviour. A random parameters logit model was developed to account for the non-independence of observations from the same respondents in the data, as well as to capture systematic preference heterogeneity of individuals. Finally, several important policy implications derived from the results are discussed. These include policies related to the design and implementation of TOD.

This chapter concludes phase three of the research, which focused on land-use and transportation interaction in the context of TOD. The first step in phase three was the development of trip production and attraction models to identify the influence of station-level attributes and characteristics of the built environment surrounding the central transit station. These models provided important insights, however, a more disaggregate approach was required to explore specific variables that influence mode choice behaviour in the context of TOD. As such, step two of phase three, included the design of the Living Near Transit Survey, modelling of the collected data, and review of the policy implications from the results. This concludes the examination of land-use and transportation interactions in the three contexts of two-worker households, rising transportation costs, and TOD.
CHAPTER 9

9 Conclusions

9.1 Chapter Overview

This chapter concludes the dissertation and a summary of the research is presented in Section 9.2. The major contributions of the research are highlighted in Section 9.3 and ideas for future research are identified in Section 9.4.

9.2 Research Summary

This dissertation examined land-use and transportation interactions in the contexts of two-worker households, rising transportation costs, and TOD. It is widely acknowledged that a two-way interaction exists between land-use and transportation systems, which is manifested in several different ways. The impact of land-use on transportation can be understood when considering that travel demand is derived from the need to participate in activities that occur in places throughout urban areas. The reverse impact of transportation on land-use is less understood likely due to the much slower rate at which land-use changes are observed. A proper understanding of the linkage between the two systems is essential to predict future transportation demand, as well as to inform and assess policies concerning integrated land-use and transportation planning.

An important distinction was made regarding the type of research carried out in this dissertation. According to Wegner and Fuerst (1999), there are two types of research on land-use and transportation interactions. There are empirical studies on the relationship between urban form and travel patterns that typically examine hypotheses about the effects of certain land-use characteristics on aspects of the transportation system (i.e. the effect of density on transit trip generation). There are also empirical studies that consider the reverse impact of transportation on land-use, however, they are far fewer (i.e. the effect of accessibility in home location choice). The other type of research on land-use and transportation interactions uses integrated models, which simulate human decision making and its consequences over a period of time in an urban
area. This dissertation falls into the former category of empirical studies on land-use and transportation interactions. The dissertation consisted of several empirical studies that examined the two-way interactions in the three different contexts. These three contexts are important to consider for social, economic and environmental sustainability and also provide a holistic understanding of this research topic.

To begin with, a thorough review was conducted of the relevant studies in existing literature to identify notable gaps. Following this, a conceptual framework consisting of three phases was developed to address the notable gaps. Phase one focused on the context of two-worker households; phase two examined the context of rising commuting costs, and phase three considered the context of TOD. The conceptual framework was designed to carry out two primary functions: 1) study land-use and transportation interactions by conducting empirical studies of household and individual behaviour in response to changes in the transport and land-use systems; and 2) use the findings of the research to provide insights into integrated land-use and transportation policies.

In the first phase of the research, the context of two-worker households was explored. Empirical models were developed to investigate the factors affecting the HWSC of two-worker households. In the first research step of phase one, joint econometric models were developed to capture the influence of endogenous commuting modal accessibility on the HWSC of two-worker households. Data for these models were obtained from the 2011 household travel survey conducted in the NCR. The second research step of phase one developed regression models to examine the role of spatial configuration on commuting trade-offs between individuals in two-worker households. In conducting these analyses, it was possible to study the influence of the above-noted aspects related to the transportation system (commuting modal accessibility and commuting trade-offs) on the land-use configuration of two-worker households. These analyses utilized geometrical variables to describe the HWSC of two-worker households, which in turn provided a unique way to explore the relationship between land-use and transportation.

Another important aspect of the transportation system is the cost associated with commuting from home to work. Commuting costs are related to accessibility, which in transportation literature is often interpreted only in terms of physical proximity of a location to activity
opportunities. As such, in the second phase of this research, the context of rising commuting costs was explored. Empirical models were developed to examine household choices under the hypothetical scenarios of increasing commuting costs. More specifically, home relocation, mobility tool ownership choice, and home location choice relative to workplaces were examined in these scenarios. Data for these models were obtained from the CHOICE survey, which collected stated preference data from households in the GTA. In using this context, it was possible to examine the influence of a transportation system attribute on land-use, in particular on households’ home relocation and home location choices relative to workplaces. Using this approach, it was possible to explore the effects of a high range of commuting costs and to assess whether these costs would initiate a process of reverse suburbanization.

Acknowledging that there is a two-way interaction, in the third phase of this research, the context of TOD was explored. TOD is an urban design model that integrates land-use and transportation. This phase of the research examined the influence of TOD on travel choices. Initially, regression models were developed to assess the influence of station-level attributes and built environment characteristics on rail ridership with walk access and walk egress. The data used for these regression models were obtained from the 2014 GO Rail Passenger Survey administered by Metrolinx. Due to the need for a more disaggregate level analysis, the Living Near Transit survey was designed to collect stated preference data from respondents who lived within a walking catchment area of the GO Transit rail stations in the GTHA. The collected data from the Living Near Transit survey was used to develop a behavioural model that examined the factors that influence mode choices in the context of TOD.

The empirical studies included in this dissertation used four different data sets and two different study areas. As stated previously, phase one utilized data from the NCR to develop joint econometric models to explore the relationship between commuting modal accessibility and the HWSC of two-worker households. Phase two utilized the CHOICE survey data from the GTA to develop discrete choice models that examined household choices in response to rising commuting costs. The first step of phase three used the GO Rail Passenger Survey conducted in the GTHA, which is slightly larger than the study area of the previous phase of research (GTA). In the final step of phase three, the Living Near Transit survey was designed to collect disaggregate data from respondents who lived within a one-kilometre radius of GO Transit rail
stations in the GTHA. The collected data was used to develop a behavioural model of mode choices in the context of TOD.

9.3 Research Contributions

The research contributions in this dissertation are categorized as novel research methodologies and new findings. The research methodology contributions included empirical studies that investigated specific relationships and contexts not previously studied or reported in the existing literature. The new findings contributed by this dissertation included modelling results which provided insights into land-use and transportation interactions, as well as the application of those results in assessing land-use and transportation policies. The major contributions of this dissertation are summarized below:

1) The literature review presented in this dissertation identified notable gaps in the existing research on two-worker households. Household level commute mode choices and the HWSC of two-worker households have not been jointly explored in empirical models. Therefore, in Chapter four, a joint econometric modelling framework was developed to study the relationship between endogenous commuting modal accessibility and the HWSC of two-worker households. Furthermore, although geometrical variables such as angle have been used in previous research to describe the spatial positioning of two-worker households, its relationship to the transportation system has not been empirically examined. The research presented in Chapter four contributed to the existing body of literature by using a novel methodology to empirically examine that relationship, which contributes to the understanding of land-use and transportation interactions.

2) The research findings in Chapter four provided new insights into the relationship between commuting modal accessibility and the HWSC of two-worker households. In particular, the modelling results indicated that higher modal accessibility has a positive association with widening angle and reducing household commute distance. Wider angles and shorter household commute distances are both indicators of optimal home location, strictly in terms of household commuting distance. The policy implication suggested from this result places
importance on expanding the coverage of public transit service as this would increase modal accessibility of a greater number of households.

3) Chapter five of this dissertation examined commuting trade-offs of two-worker households using Cobb-Douglas and multi-level regression models of household commute distance, which is a methodology not previously used for this research question. Furthermore, the models used stated preference data of households in the GTA. Stated preference data had also not previously been used to explore this research question. Therefore, the research presented in Chapter five contributed to the existing literature on two-worker households by examining their commuting trade-offs using a novel methodology and data type in the context of the GTA.

4) The research findings in Chapter five revealed an inverse relationship between household commute distance and the difference between longest and shortest individual commutes, which confirmed that two-worker households make commuting trade-offs in order to reduce overall commute distance. This is a new finding of two-worker households which has an important policy implication. Some research argues that policies proposing jobs-housing balance are not achievable due to the presence of two-worker households and their inability to optimally locate near both workplaces. However, this research challenged that argument by revealing that two-worker households will adjust their home locations in order to be closer to one of the two work locations, thereby achieving some level of jobs-housing balance.

5) Chapter six investigated the impact of transportation on land-use through the lens of rising commuting costs. This reverse impact of transportation on land-use is not adequately understood through empirical research. Furthermore, although commuting costs have been considered in previous research, a broad range of costs has not been adequately studied to determine its impact on land-use. Therefore, the research presented in Chapter six contributed to the existing body of literature by developing two discrete choice models that examined household choices in the context of significant increases in transportation costs. The first model was a combined discrete choice model which considered the alternatives for households to adjust their mobility tool ownership and/or choose home relocation in the
face of rising commuting costs. The second model was a home location discrete choice
model that considered the direction of home location relative to workplaces, i.e. relocating
closer to, further from, or staying in the same area as the current home location. This
methodology is a novel approach to examining the less understood impact of transportation
on land-use.

6) The research findings in Chapter six provided important insights about the interactions
between land-use and transportation. The *a-priori* hypothesis was that rising commuting
costs would encourage household relocation closer to workplaces to mitigate transportation
costs, thereby initiating reverse suburbanization. However, the combined discrete choice
model revealed that high income was positively correlated with the choice to relocate.
Furthermore, the home location discrete choice model revealed that greater real estate price
differentials between workplace and home locations induced households to move farther
away from workplaces, thus perpetuating urban sprawl. A policy implication derived from
these modelling results is the improvement to residential affordability, such as through the
provision of non-market driven housing.

7) Chapter seven investigated the impact of land-use on transportation in the context of TOD.
The literature review presented in this dissertation revealed that although there is extensive
research on TOD, empirical studies are limited. Furthermore, the existing empirical studies
that employ trip generation models do not isolate trips that started or ended with walking.
Walk access and egress are important objectives of TOD and especially for Metrolinx.
Therefore, two separate empirical models were developed to identify station-level
characteristics and built environment attributes that influence trip production and trip
attraction with walk access and egress, respectively.

8) The research findings in Chapter seven revealed that certain station-level characteristics
and built environment attributes have significant impacts on rail ridership with walk
access/egress, which therefore have implications for the design and implementation of
TOD. The research found that the number of bus arrivals at GO Transit rail stations had a
negative impact on rail ridership with walk access. Although bus access is preferred over
car access from a policy perspective, TODs should be designed with limited bus stops
within its walking catchment area to avoid creating competition with the more desirable walk access mode. The research also found that higher parking utilization has a positive association with rail ridership with walk access, meaning that parking facilities at capacity create an incentive to walk. An implication derived from this result is that Metrolinx should not prioritize expanding parking facilities at the GO Transit rail stations if their main objective is to improve walk access for residents in the TOD walk catchment area.

9) Chapter eight also investigated TOD but did so using a behavioural analysis to identify specific factors that influence mode choices. The literature review in this dissertation identified that no existing studies had used stated preference data to investigate mode choice behaviour of residents within walking catchment areas of rail stations. Therefore, Chapter eight presented the Living Near Transit survey, which was developed and conducted to collect disaggregate stated preference data from residents within a walking catchment area of GO Transit rail stations. Respondents selected main mode and access mode choices in hypothetical scenarios with varying characteristics associated with TOD. This research used the collected data to develop a random parameters logit model, which examined main mode and access mode choices.

10) The research findings in Chapter eight identified demographic factors, travel attributes, and TOD characteristics that influence mode choice behaviour of residents in the walking catchment area of GO Transit rail stations. The descriptive analysis of the data collected from the Living Near Transit survey revealed a high proportion of two-worker households in the study area relative to the average across the GTHA. This is significant for Metrolinx considering the modelling results indicated that residents from two-worker households are likely to choose carpool as the GO Transit access mode. Furthermore, the modelling results indicated that higher parking costs at the station also encourages carpool access. Given the high proportion of two-worker households and their propensity to use carpool access, Metrolinx should prioritize carpool designated parking and use some amount of paid parking. This would help achieve a general TOD and Metrolinx specific objective to reduce overall auto usage by reducing single occupancy auto use. The above findings have not previously been reported and should be considered by planning agencies in the design and implementation of TOD.
9.4 Future Research and Recommendations

The modelling results in this dissertation advanced the understanding of land-use and transportation interactions and provided insights into related policies. The research findings are important in their own right and form the basis of further research. The modelling results in Phase one of the research revealed the importance of geometrical variables in describing the HWSC of two-worker households. The HWSC can be used as an indicator of home location optimality from the perspective of reducing commuting distances. The results indicated that higher commuting modal accessibility increases angle and reduces household commute distance, resulting in a more optimal HWSC. Therefore, future research should utilize the HWSC as an explanatory factor in home location choice modelling for two-worker households. This type of modelling requires segmentation of the population into two groups, namely single worker and two-worker households. The results of this study may also have important implications for energy consumption and greenhouse gas (GHG) emissions, which is a critical area of research considering the issue of climate change. Although energy consumption and GHG emissions were not considered in Phase one, these two factors are clearly a byproduct of commuting distance and should be considered for future research.

The first step of Phase one used the 2011 O-D household travel survey of the NCR to examine the relationship between commuting modal accessibility and the HWSC of two-worker households. Future research could examine this relationship by utilizing a methodology that relies on O-D surveys from multiple years. This would allow for the creation of a pseudo-panel dataset that enables the examination of temporal and spatial variations in the factors affecting the HWSC.

A challenge faced in the data collection for the second step of Phase one arose out of the extensive nature of the survey and the burden created for respondents to complete the survey. Additionally, two-worker households are a subset of the population which further limited the number of records that could be used in the study. Despite these limitations, the reliance on stated preference data is a contribution of this study as it directly enables the analysis of commuting trade-offs made by existing two-worker households. It is possible for future research to overcome the challenge of limited records by using a pseudo-panel dataset extracted from
different years and regions, which has the added benefit of enabling the examination of temporal and spatial variations.

Phase two of the research developed discrete choice models to examine household choices in the context of rising transportation costs. One of the models examined home location choice that considered the direction of home location relative to workplaces, i.e. closer to, further from, or staying in the same area as the current home location. This modelling framework highlighted the effect of real estate price differentials on the direction of movement of households. Future research should examine that effect further by developing a residential location choice model with two components, namely a location choice model and a dwelling type choice model, that consider home prices. A nested logit model is one possible modelling structure to conduct this future research.

The first step of Phase three utilized the 2014 GO Rail Passenger survey data provided by Metrolinx to develop a station-level analysis of rail ridership with walk access and egress. Future research could employ a longitudinal methodology using data collected from multiple years and different urban regions. With this type of data, a random effects analysis could be utilized to determine the variations across time and different regions.

Step two of Phase three of the research included a discrete choice model that examined mode choice behaviour of residents within the walking catchment area of GO Transit rail stations. The modelling results provided important insights into factors related to TOD that influence travel choices. These results can be used by planning agencies to effectively design and implement TOD. However, it is also important to understand the attractiveness of living in a TOD to ensure its successful implementation. Therefore, future research should develop residential location choice models to determine who would locate in a TOD and what attributes of TOD encourage that home location choice.
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Appendix A

Living Near Transit Survey programming document

2016 LIVING NEAR TRANSIT SURVEY: ONLINE VERSION

PROGRAMMER NOTE: SURVEY WILL BE OPEN, RATHER THAN RESTRICTED TO SPECIFIC ID’S. CARD HANDOUT INVITATION WILL HAVE THE URL OF http://www.livingneargo.ca/, WHICH IN TURN WILL HAVE ONE DIRECT LINK TO THE MALATEST SURVEY START (LINK #1). E-MAIL INVITATIONS VIA GO ALERTS WILL HAVE THE URL OF […Insert URL……] AND WILL BE GIVEN A DIFFERENT LINK (LINK #2) TO THE MALATEST SURVEY START. EACH SURVEY RECORD SHOULD INDICATE WHETHER THE SURVEY WAS ACCESSED THROUGH LINK #1 OR LINK #2. INDIVIDUALS WILL BE GIVEN PROVISIONS TO SEND THEMSELVES A LINK TO THEIR OWN SURVEY.

Survey Header (Living Near Transit):

[Metrolink logo. Metrolink branding in conjunction with the University of Toronto/ train graphic.]

Survey Footer (displayed on every screen after the introductory screen):

For assistance with the survey, call [TOLL-FREE NUMBER] or contact […Insert Email Address]


If you can’t complete the survey right now, return later and continue from where you left off! Click here to send yourself a link to your personal survey so that you can continue this same survey later.

Send Link Pop-Up

You have asked to receive a link for your personal survey so that you can re-enter the survey later. Please enter your e-mail below, then click “Send Link.” Within a few minutes, you will receive an email with a direct link to your own personal survey, so that if you have to leave, you can resume your survey later from exactly where you left off.

We respect your privacy. Your email address will only be used to send you a link to the survey you have just started. Your email address will not be used for any other purpose and will be deleted.

Send Link E-mail

Subject Line: 2016 Living Near Transit Survey
You have requested a link to your personal survey for the Living Near Transit Survey. Click on the link to resume your survey where you last left off.

**individual survey link**

To protect the privacy of your survey responses, do not share this link with anyone else.

Thank you for your participation in this important research.

If you experience any difficulty completing the survey online, please contact [MALATEST TOLL-FREE NUMBER] for assistance or e-mail

[...Insert Email Address]

If you have any questions about Metrolinx’s research on the mobility of residents living near GO Transit stations, including this survey, please contact (416) 869-3600 ext. 4060 or MarketingResearch@gotransit.com.

**Screen A1:**

**Introductory Screen:**

This survey is conducted by Metrolinx in conjunction with the University of Toronto. Your feedback will be used for planning new services and urban development around GO Transit stations and improving the existing services. Your answers will be kept in strict confidence.

Completing this survey will automatically enter you in a contest for a chance to win one of ten $200 transit fare vouchers. See details at the end of the survey.

If you have any questions about Metrolinx’s research, including this survey, please contact (416) 869-3600 ext. 4060 or MarketingResearch@gotransit.com.

If you experience any difficulty completing the survey online, please contact [MALATEST TOLL-FREE NUMBER] for assistance or email

[...Insert Email Address]

We appreciate your input!

**VALUES ARE GIVEN FOR CERTAIN QUESTIONS TO MATCH PREVIOUS DATA FOR COMPARABILITY. IF VALUES NOT GIVEN, THEN APPLY STANDARD RESPONSE VALUE NUMBERING CONVENTIONS**
PART A – QUALIFY

Screen A1:

Qualify

Do you live within 1 kilometre of a GO Rail station?

1 Yes

2 No  [SURVEY TERMINATION]

Are you a worker?

1 Yes

2 No  [SURVEY TERMINATION]

PART B – TRIP DETAILS OF WORK TRIP

Screen B1

Household Vehicles

How many vehicles does your household have available for personal use?

1 Zero

2 One

3 Two

4 Three

5 Four or more

99 Prefer not to answer
Household Bikes

How many bicycles does your household have available for personal use?

- 1 Zero
- 2 One
- 3 Two
- 4 Three
- 5 Four or more
- 99 Prefer not to answer

Household Workers

How many workers (who have a work place outside the home) are there in your household?

- 1 Zero
- 2 One
- 3 Two
- 4 Three or more
- 99 Prefer not to answer

[IF Household Workers = 0] only ask the following remaining questions from Parts B and D of this survey:

From Part B:

Home Location Postal Code

Driver’s Licence

Presto Card
From Part D:

Ask all questions in Part D except for:

Employment status

Work duration

Screen B2

HomeLocationPC

Please enter your home location?

City/town: 

Address: 

Postal Code: (ex. A1B 2C3)

WorkLocationPC

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

Please enter your work location?

City/town: 

Address: 

Postal Code: (ex. A1B 2C3)

Screen B3

Driver’s Licence

Do you have a driver’s licence?

1 Yes

2 No
**Presto Card**

Do you have a Presto Card?

- 1 Yes
- 2 No

**Screen B4**

**Mode**

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

How did you travel from home to work on your most recent work commute trip? If you travelled using separate modes (e.g., car, local transit), please select the primary mode you used for most of the trip. The primary mode is the travel mode in which you spend the highest proportion of your total travel time.

- 1 driving private car
- 2 ride from a household member (car passenger) or carpool with someone not in your household
- 3 local transit
- 4 GO Transit
- 5 use a taxi or other ride-haul service (e.g. Uber)
- 6 other

**Work Arrival**

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

What is your employer’s expectation of your arrival time to work?

If your employer does have an expectation of your arrival time, what time do you usually target for your arrival at work? If you do not know the exact time, please estimate.

-  a.m.  p.m.

HH   MM
Car for Work

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

Is a car needed/required for your work?

☐ 1 Yes

☐ 2 No

Screen B4A

Access GO station

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

What is the nearest GO rail station to your home? (Please use the GO transit map below for reference).

Approximate distance

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

What is the approximate distance from your home to the nearest GO rail station (in metres)?

Egress GO station

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

What is the nearest GO rail station to your work location? (Please use the GO transit map below for reference).

[Instruction to programmer: Please provide a diagram of the GO transit network superimposed on a map showing major street and cities in the Greater Toronto Area. This map will assist the respondent in determining the closest GO rail stations to their home and work locations.]

Screen B5

Total Trip Time

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

Please enter the following information for your most recent typical trip from home to work (door to door):
1 If GO Transit was your primary mode:

Left home at

HH  MM

Duration of your trip

HH  MM

2 If driving a private car was your primary mode:

Left home at

HH  MM

Duration of your trip

HH  MM

3 If car passenger/car pool was your primary mode:

Left home at

HH  MM

Duration of your trip

HH  MM

4 If local transit was your primary mode:

Left home at

HH  MM

Duration of your trip

HH  MM

5 If taxi or other ride-haul service was your primary mode:
Screen B5A

Trip Time Components

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5 and MODE = GO Transit (If GO Transit was your primary mode)]

Please specify the time spent travelling to and from GO stations during your most recent work commute trip (from home to work):

Access mode:

(what was the mode used to travel from your home to the GO station)

1 drive and park

2 car passenger/car pool passenger

3 cycle

4 walk

5 local transit

6 other
Access Time (the total travel time from your home to the GO Station): □□ HH MM

Walk Time (the total walk time from your home to the local transit stop): □□ HH MM

*Ask only if Access Mode is local transit

Wait Time (the time you waited at the local transit stop): □□ HH MM

*Ask only if Access Mode is local transit

How did you get to work after you got off at your last GO station of your trip?

(1) walk
(2) local transit - subway
(3) local transit - streetcar
(4) local transit – bus
(5) cycle
(6) taxi or other ride-haul service
(7) other

If walk,
the walk time to get to work: □□ HH MM

If local transit,

Egress Time (the total travel time from the last GO station to your work): □□ HH MM

Walk Time (the total walk time from the last GO station to your work): □□ HH MM

Wait Time (the time you waited at the local transit stop): □□ HH MM
Screen B6

Total Trip Cost

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5] Please enter the total one-way trip cost (from home to work but excluding parking cost at your work if applicable) of the primary mode of transit you used for your most recent work trip. The primary mode is the travel mode in which you spend the highest proportion of your total travel time.

[Programming instruction: If possible, please set up the clarifying explanations as mouseovers]

1 If GO Transit was your primary mode:

Cost of parking at GO Station:  
(enter 0 if not applicable)

GO Transit fare:  

local transit fare to GO Station:  * This is the fare for using local transit to access the GO train at start of trip  
(enter 0 if not applicable)

local transit fare from GO Station:  * This is the fare for using local transit to travel from the last GO station to your work.  
(enter 0 if not applicable)

Total:  [Total cost to appear in this field when above 4 are provided; respondent not able to manually fill out this box]

Local Transit fare is the cost of taking local transit to access the Regional GO Transit station. Respondent
can enter 0 if local transit was not used as the access
t mode]

2 If a private car was your primary mode: [ ]

*This is your out-of-pocket running cost for
fuel, but not including maintenance or insurance

(do not include parking costs at work)

3 If car passenger/carpool passenger was your primary mode: [ ]

( do not include parking costs at work):

4 If local transit was your primary mode:

5 If taxi or other ride-haul service was your primary mode:

6 If other primary mode:

Screen B7A

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, Sand IF VALUES PROVIDED IN CODE 2 (If private vehicle is primary

mode)]

Parking Cost

On average, what is the daily parking cost at your work location? [ ]

Does your employer pay for your parking cost at your work location?

1 Yes

2 No

3 Partially (identify how much)

Screen B8

Travel Cost Compensation

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

Does your employer pay for your daily trip expenses (fuel and other driving cost or transit fare)?
1. Yes
2. No
3. Partially (identify how much):

Screen B9

Summer Access

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

Is your primary access mode, [Insert answer to “Access Mode”], also your primary access mode in the summer months?

1. Yes
2. No

If no, then please identify which one is this:

1. drive and park
2. car passenger/car pool passenger
3. cycle
4. walk
5. local transit
6. other

Screen B9A

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

[ASK ONLY IF Summer Access = NO]

Summer Access Mode

What is the primary travel mode you use for getting to work in the summer months?
○ 1 driving private car
○ 2 ride from a household member (car passenger) or carpool with someone not in your household
○ 3 local transit
○ 4 GO Transit
○ 5 use a taxi or other ride-haul service (e.g. Uber)
○ 6 other

ScreenB10

[IF Household Workers = 2] repeat the following individual specific questions for the second primary income provider for the household:

[There needs to be some survey design work here on this side of things.]

- Is the intent to ask the stated preference questions of the ‘second primary’ income provider? Or just to gather the same pieces of information for reference?
- Needs an intro to explain that the questions are to be asked of the second primary income provider.
- Also, can the current survey respondent ever fill out the survey by proxy, i.e., on behalf of the second breadwinner? If so, then there should be a question to confirm whether this part of the survey is being filled out by the second breadwinner, so that you get a sense of the reliability of the results. One caution: while it may be reasonable for someone to give answers regarding another householder’s origin, destination, modes of travel etc., it may not be possible to give accurate answers on the exact departure times and/or.
- Note that asking these questions of a second breadwinner may result in some surveys being abandoned before they get to the experiments – e.g., if the second breadwinner is not available to do the survey at the same time, it may get deferred and never finished.
- Also, it would be better to position the second breadwinner questions after the first person has completed their experiments, so at least you get a completion with the first respondent even if the second one never gets around to completing their portion of the questions.

From Part B

WorkLocationPC

Driver’s Licence

Presto Card

Mode

Work Arrival
PART C – STATED PREFERENCE

You will now be presented with six hypothetical scenarios that are based on responses from previous questions.

Each scenario contains all possible travel modes (presented in columns) with corresponding trip details that may affect your commuting mode choices (presented in rows).

We would like you to consider each travel mode scenario as a potential real-life situation. Please carefully compare all details of each mode, then make a choice that you would make in real life if the same situation existed.

At the end of each choice, we would also like you to rank your confidence on the choice that you just made in terms of how consistent your choice in reality would be if the same situation appears in real life.

Simplified Example

[Programming instruction: this can just be a picture, there is not a choice to be made]

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>Auto Driver</th>
<th>Carpool</th>
<th>Local Transit</th>
<th>GO Transit - Local Transit Access</th>
<th>GO Transit - Walk Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$3.00</td>
<td>$2.50</td>
<td>$2.80</td>
<td>$5.50</td>
<td>$4.50</td>
</tr>
<tr>
<td>Time</td>
<td>15 minutes</td>
<td>25 minutes</td>
<td>20 minutes</td>
<td>10 minutes</td>
<td>15 minutes</td>
</tr>
</tbody>
</table>
SCENARIO 1:

Consider each scenario as a potential real-life situation. Please carefully compare the different travel mode alternatives, with their different costs, times, and other details. Then make a choice that you would make in real life if you had the same travel modes available to you.

[Programming instructions: record all of the unique values used in the table for later use in the analysis.]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VARIABLES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Travel Cost ($) (Includes parking cost at destination)</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>Additional Parking Cost at Access GO station ($) (not applicable for car pool Option)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>3 levels</td>
<td>-</td>
<td>-</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Additional Local Transit-GO Transit Access Fare ($) (cost of local transit fare used to access GO station)</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>--</td>
<td>--</td>
<td>Current</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Walk Time (minutes) (Once you have reached the grounds of the GO station, what is the time it takes you to walk to your platform)</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>Wait time (minutes) (the time you wait on the platform for your train to arrive)</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>3 levels (based on current wait time, 3 values will be created)</td>
<td>3 levels (based on current wait time, 3 values will be created)</td>
<td>3 levels (based on current wait time, 3 values will be created)</td>
<td>3 levels (based on current wait time, 3 values will be created)</td>
<td>3 levels (based on current wait time, 3 values will be created)</td>
</tr>
<tr>
<td>Access Time (minutes) (the time it takes you to reach the GO station from your home)</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>In-vehicle travel time(minutes) (the time it takes on your main mode of travel to reach your destination)</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>Egress Time (minutes) (the time it takes to travel from the egress GO station to your destination)</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>TOD FACTORS</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td><strong>Availability of Bicycle Parking at GO station</strong></td>
<td>3 levels</td>
<td>current</td>
<td>minus 25%</td>
<td>and current minus 50%.</td>
<td>Or Make ranges: 0 to 200m, 200m to 400m</td>
<td>3 levels current minus 25% and current minus 50%.</td>
<td>Or Make ranges: 0 to 200m, 200m to 400m</td>
<td>3 levels current minus 25% and current minus 50%.</td>
</tr>
<tr>
<td><strong>Distance from your home location to the bus stop nearest your home (metres)</strong></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>The time between buses at the bus stop nearest your home (minutes)</strong> (how frequently buses depart the bus stop)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**YOUR CHOICE:**
You may choose only one

Confidence in Choice: Please rank your confidence on the choice that you just made in above scenario (Please select only one) Here 1 indicates uncertain and 4 indicates fully certain

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
</table>

**PART D – PERSONAL INFORMATION**

Screen D1

Gender

What is your gender?

- O 1 Male
- O 2 Female
- O 3 Other
- O 99 Prefer not to say
Age

What is your age (in years)?

- Prefer not to say

Marital Status

What is your marital status?

- Single
- Married
- Widowed
- Separated
- Divorced
- Prefer not to say

Employment Status

What is your employment status?

- Full-time
- Part-time
- None

Screen D1

[IF employment status = full-time or Part-time, ASK]

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

Work duration
What is your daily average work duration (in hours)?

- [ ] Prefer not to say

**Industry**

[Ask if Household Workers >= 1 i.e., codes 2, 3, 4, 5]

[Programming instructions: use mouseover text for the examples in brackets]

What industry is your current occupation?

- [1] Agriculture, forestry, fishing and hunting
- [2] Mining, quarrying, and oil and gas extraction
- [3] Utilities (power generation, natural gas distribution, water, sewage)
- [4] Construction
- [7] Transportation and warehousing
- [8] Information and cultural industries (arts, publishing, film, telecoms, internet)
- [9] Finance and insurance
- [10] Real estate, rental and leasing
- [11] Professional, scientific and technical services (accounting, architecture, engineering, design)
- [12] Management of companies and enterprises (exercising control, managing companies either directly or through subsidiaries and/or influencing the management decisions of businesses)
- [13] Administrative and support, waste management and remediation services (administration, hiring and personnel placement, preparing documents, arranging travel, security and surveillance, cleaning, collection, treatment and disposal of waste materials, remediating polluted sites, cleaning septic sites, operation of recycling facilities)
- [14] Educational services
- [15] Arts, entertainment and recreation
- [16] Accommodation and food services
- [17] Other services (repair and maintenance, personal care services, private home services, funeral services, religious, civic and charitable organizations)
- [18] Public administration

- [77] Other, specify: ____________________________

- [99] Prefer not to say

**Screen D2**

**Transit Pass**

Do you have a local transit pass?
1 Yes
2 No
Prefer not to say

**Housing Type**

What is your housing (dwelling unit) type?

1 Detached house
2 Semi-detached house
3 Townhouse
4 Low-rise Apartment/Condo (4 stories or less)
5 Mid-rise Apartment/Condo (5-11 stories)
6 High-rise Apartment/Condo (12 stories or more)
Other, specify: _____________________

**Size of Home**

What is the size of your current home (in square footage)?

Don’t know
Prefer not to say

**Tenure**

What is the tenure of your current home?

1 Rent
2 Own
Prefer not to say
[IF tenure = own, ASK]

**Age of home**

What is the age of your current home (year of date)? [ ]
- Don’t know
- Prefer not to say

**Move in date**

When did you move in to your current home (month and year of date)?
- Month [ ]
- Year [ ]
- Prefer not to say

**Parking spaces**

What are the total number of parking spaces available to you at your current home? [ ]
- Don’t know
- Prefer not to say

**Bedrooms**

How many bedrooms are there at your current home? [ ]
- Prefer not to say

[IF primary mode of travel = private car, ASK] Refer to question in Part A regarding primary mode

**Car type**

What is your car type (the car that you use for commuting purpose mostly)?
- 1 Compact/ subcompact
2. Midsize
3. Large-size
4. SUV
5. Pickup truck
6. Prefer not to say

Household income

What is your gross household’s total annual income (in Canadian dollars before tax)

1. $29,999 or below
2. $30,000 - $59,999
3. $60,000 - $89,999
4. $90,000 – $119,999
5. $120,000 – $149,999
6. $150,000 – $179,999
7. $180,000 – $209,999
8. $210,000 or more
9. Prefer not to say

ScreenD3

Refer to question in Part B regarding number of household workers. [IF Household Workers = 2] repeat the following individual specific questions for the second primary income provider for the household:

Gender

Age

Marital Status
Employment Status

Work duration

Industry

Transit Pass

Car type

PART E – COMMENTS, PRIZE DRAW, SURVEY END

Screen F1

GeneralComments

Do you have any other comments?

Screen F2

PrizeDraw

Do you wish to enter for a chance to win one of 10 GO Transit fare vouchers of $200 each?

☐ 1 Yes

☐ 2 No

Screen F2A

Please provide your contact details, so that we can enter your name in the prize draw.
Your privacy is important to us! Your contact information is stored in a separate database and will not be associated with your answers to the survey in any way. Your information will not be used for any purpose other than the prize draw and will be deleted once prizes are awarded.

- First name: 
- Last name: 
- Phone number: 
- Email: 

**Screen F3**

Click ‘submit’ to save your survey information.

Once you click ‘Submit’, this survey will no longer be accessible. Your data will be stored securely, and your privacy will be protected.

Feedback is collected by Metrolinx for the purposes of developing and implementing management strategies and programs relating to transit and transportation demand under the authority of the Metrolinx Act, 2006 (section 16(1)(c)). Questions regarding this collection should be directed to the Manager, Research and Business Solutions, 20 Bay Street, Suite 600, Toronto, Ontario M5J 2W3, Telephone (416) 8693600 or email to MarketingResearch@gotransit.com.

**Screen F4**

Your responses to this survey have been submitted.

Thank you for your participation!