Residential Location Choices in an Unaffordable City: Evidence from Key Workers

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Abstract

Choosing where to live is one of the most important questions that individuals will consider during their lifetimes. Understanding the answer to this deceptively simple question can offer insights into how urban cities can improve their transportation infrastructure, housing construction and spatial planning. In urban economics, the conventional theory of residential location choices is a utility optimisation decision for single worker households choosing a residential location. Provided that all commuting costs and prices for land and rents depend on location, residential location decisions are thus subject to these constraints. However, from the von Thünen (1826) model on urban land use to Alonso (1964), Mills (1967) and Muth's (1969) bid-rent theory, most literature on residential location choices largely neglects the differences between residential tenure type and household composition and does not capture the uncertainty that households face during the decision process of choosing residential location.

This thesis uses two-level data, including aggregate and individual census data from 2001 to 2018 for Auckland, New Zealand, to address three questions related to residential location choices: 1) What role does home purchase affordability play in commuting patterns and spatial distribution across workers? 2) Do occupational differences and multiple workers in the household matter in residential location choices? and 3) To what extent do suboptimal residential location choices lead to a spatial mismatch amongst key worker homeowners? Key workers are chosen as the focus of this thesis because this group of low- to moderate- class professionals, who provide essential services for the community, usually is not qualified for subsidised homeownership but are not able to afford to access homeownership near their job locations at the market price in cities where housing is severely unaffordable. According to the 2020 housing affordability survey (Blain & Holle, 2021), Auckland was ranked as the fourth least affordable market globally. The COVID-19 pandemic has further highlighted the dependence of cities and their populations on these workers.

The contribution of this thesis is twofold. First, this thesis extends Kain's (1968) spatial mismatch hypothesis to consider the occupation of households. The aggregate census data analysis in this thesis confirms that workers' sub-optimal residential location choices will cause a jobs-housing mismatch and lead to negative externalities that create additional commuting costs. The results indicate that for key workers, a one per cent increase in housing unaffordability (i.e., mortgage repayment relative to the annual income) results in an extra two-kilometre commuting distance – the equivalent to a $90 million deadweight loss a year. Second, this thesis also fills the knowledge gap by examining households' residential rental location choices with multiple potential breadwinners under uncertainty. By extending Crane's (1996) residential locational choice model, this thesis develops a two-worker, two-period, two-centre (2W×2P×2C) model to demonstrate the optimal residential rental location choices in multiple worker households. Using the Integrated Data Infrastructure (IDI) from Statistics New Zealand, empirical tests of the model suggest that multiple-worker households are less inclined to pay a rental premium to live close to the city centre than are single-worker households. To further understand how the characteristics of individual wage earners affect their residential choices under uncertainty, the rigidity of their job locations and work hours are analysed. The individual-level analysis confirmed the theoretical prediction that key workers with higher certainty job locations are less willing to pay higher rent to live close to the city centre. In contrast, workers taking public transport or working long hours prefer to pay a premium to reside in city centres, thus enabling shorter commutes and more job opportunities.

Residential location choice is a crucial driving force in urban dynamics. The evidence from key workers in one of the least affordable cities in the world articulates that to better analyse the choice of residential locations, homeownership affordability (versus renter affordability), job locations uncertainty, and commuting uncertainty are pivotal in the theory of residential location choices. In addition, the traditional assumption of single-worker households also prevents us from understanding the big picture of residential mobility in an urban city. This thesis gives prominence to the imminent need to refine the existing residential location choice models in the literature. The estimation of social costs associated with the housing-induced spatial mismatch in this thesis also pinpoints that the cost of homeownership could be exorbitant for an urban city, reminding us that when solving "The Problem of Social Costs" (Coase, 1960), one must analyse the costs of the action involved.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

Abbreviations	Explanations
AIFS	Auckland Integrated Fare System
ANZSCO	Australian and New Zealand Standard Classification of Occupations
CBD	Central Business District
FIN	Finance-insurance workers
GIS	Geographic Information System
IDI	Integrated Data Infrastructure
KEY	Key workers
LTV	Loan-to-value
NGO	Non-government Organisation
NPS-UD	National Policy Statement on Urban Development
NZDep	Socioeconomic deprivation in New Zealand
OD	Origin-Destination
POI	Points of interest
RBNZ	Reserve Bank of New Zealand
RET	Retail trade workers
SPI	Spatial mismatch index
Stats NZ	Statistics New Zealand
SUR	Seemingly unrelated regression

Chapter 1

Introduction

People have lived on Earth for thousands of years. Throughout history, people have chosen to settle in particular locations for many pragmatic reasons, and for just as many reasons, they have chosen to move to settle in other locations. Cities, road networks, agricultural areas, industrial regions, and transportation hubs all contribute to people's choices of residential location the world over. Of the various factors that affect people's preferred place of residence, housing affordability is amongst the most critical constraints for households to decide where they live in modern urban areas.

This thesis focuses on a particular group of the working population called "key workers" in New Zealand (also known as "essential workers" in other nations), examining their preferences and the constraints on their choices concerning residential location. Key workers usually have inequitable access to homeownership, even though their contribution to society is essential. Being low- to moderate-income workers who work in the public sector and provide services essential to the continued functioning of the urban economy and development, these workers consistently earn too much to qualify for subsidised housing but too little to purchase private housing at market prices. Many local public authorities in Commonwealth nations, such as in London, England, and Melbourne, Australia, have faced imminent problems retaining key workers owing to the gap between their lower income levels and their difficulty accessing affordable housing options close to their workplaces.

Amidst growing concern about the retention of key workers in high-cost metropolitan areas, this thesis shows how housing (un)affordability affects residential location choices, commuting patterns and, in general, the choice of residential locations under uncertainty. Its findings will allow urban planners, policymakers and stakeholders to identify ways of helping key workers live near to and access their jobs.

1.1 Background

House prices have been highly unaffordable in New Zealand over the past decade (Blain & Holle, 2021; Hartwich, 2017), and Auckland, the largest city in New Zealand, is no exception. Amidst sustained rampant house price growth in Auckland, many working households now face significant challenges obtaining appropriate, affordable housing, particularly for purchase. According to Statistics New Zealand, homeownership rates have fallen for all age groups since the early 1990s, with the proportion of people living in their own homes in 2018 at the lowest figure in almost 70 years. As a result, many working households that would previously have become homeowners are now locked out of the housing market, straining rental needs (Hulse et al., 2019). Anecdotally, to cope with the lack of affordable housing near workplaces and the commute demands, many workers are limited in their choices of residence and have to reside in the city fringe and suffer long commutes, especially key workers (Fernandes, 2018).

Key workers, low- and moderate-income workers who work in the public sector and provide essential services to ensure the functioning of the urban economy and development (Batty et al., 2021; Morrison, 2003; Steele & Todd, 2004), include public sector workers such as nurses, teachers, healthcare and community service workers and other workers such as police and fire-fighters. Recent disruptions caused by the COVID-19 pandemic have highlighted cities' reliance on these workers and the risks to overall resilience when essential services are inadequately staffed or when workers who live far from the populations, they serve become unable to respond to emergencies or sudden spikes in service demands. Although many workers worked from home through national lockdowns during the pandemic, many key workers still had to commute to their workplaces.

Given the scarcity of affordable housing near workplaces and the traditional desire for homeownership, recent anecdotal evidence suggests that some key workers are moving to the city fringe or to areas with low accessibility and low house prices. This trend decreases accessibility, lengthens commutes and increases private vehicle use (Kerry Mattingly & Morrissey, 2014). On the one hand, lengthy travel and a rise in the number of workers driving their own cars will increase commuting congestion and reduce work efficiency; on the other hand, workers' tendency to move away from the inner city will cause difficulties recruiting and retaining key workers in metropolitan areas (Airey & Wales, 2019).

Certain studies have focused on key workers and analysed the housing needs of this unique working population, particularly in the United Kingdom and Australia (Morrison, 2003; Steele & Todd, 2004). Urban economy and development suffer various disadvantages amidst shortages of affordable housing and lengthy commutes, with urban planners and other policymakers caught between considerations of affordability and commuting. Unfortunately, many of the discussions about affordable housing for key workers either use aggregate data to recognise such challenges or use employee survey data to conduct case studies demonstrating the issues of affordability that key workers face. However, the nature of key workers' housing issues seems to be overlooked, with the factors affecting their decision about where to reside left unclear.

The essence of the key worker housing issue must be understood, its impacts deliberated, and policymakers provided with feasible suggestions to consider in New Zealand.

In 2013, more than 75,000 workers were employed as key workers across the Auckland region, equivalent to 17% of Auckland's total workforce. Many housing programs offer affordable housing to low-income workers, but key workers generally earn too much to qualify for social housing and affordable housing programs but too little to afford housing near their workplaces. To the best of my knowledge, no studies have focused on key workers in New Zealand, nor has research been conducted to precisely quantify the extent of this problem.

This thesis focuses on the residential location choices and spatial mismatch that key workers in Auckland face. The phenomenon of spatial mismatch in urban economics refers to the geographical disconnect between workers' place of residence and their place of work (Holzer, 1991; Kain, 1968, 1992). Although much research on spatial mismatch has focused on demographics, skills and gender, this thesis theorises the concept of spatial mismatch hypothesis in relation to occupational groups. Focusing on key workers, it proposes a novel spatial mismatch metric that captures the extent of excess commuting and measures the degree of spatial mismatch amongst key workers at the aggregate level, investigating the ways in which housing affordability constraints key workers' choice of residential location. Beyond housing affordability, this thesis also addresses the ways in which the intrinsic nature of key workers (higher certainty of job location) and their associated commuting costs affect Auckland renters' choice of residential location, using individual data.

1.2 Research objective

The spatial mismatch phenomenon has been the subject of considerable empirical and theoretical debate since Kain (1968) first described its empirical dimensions. Against the background of residential segregation of different ethnicities, inner-city African American workers suffered diminished access to employment opportunities as well as long commutes amongst those able to travel to work in the suburb. Many early discussions in the literature on spatial mismatch concentrated on ethnic minorities in the United States, investigating the mechanisms and outcomes of their spatial mismatch (Brueckner & Zenou, 2003; Gobillon et al., 2007; Weinberg, 2000). Recent studies have attempted to apply spatial mismatch to low-income workers, with a focus on skill mismatch, household types, demographic groups and gender as contributors (Fan et al., 2014; Hui et al., 2015; Zhao, 2015). Only a handful of studies on housing affordability and disadvantaged workers have looked specifically at key workers (Steele et al., 2004; Morrison, 2003; Raco, 2008), but none has considered spatial mismatch among key workers in New Zealand or quantified its extent. Two notable exceptions may be the studies by Gurran et al. (2018) and Gilbert et al. (2021), both of which focused on Australia: Gurran et al. (2018) described income levels and estimated the range of affordable housing of key workers, whereas Gilbert et al. (2021) described key worker policies around the world and sought to identify policies feasible for use in Australia. Even so, these authors failed to quantify the degree of spatial mismatch, particularly the spatial mismatch of key workers in New Zealand.

The affordability of housing is one of the constraints that key workers experience when choosing a residence, but many other factors influence their choice of residential location when they are renters. In particular, when workers are in households with multiple workers, residential location is chosen jointly by each worker in the household and is affected by the characteristics of each. When households decide on locations of residence, they consider the housing consumption changes that can be triggered by changes in worker’s circumstances or housing market conditions. Housing location decisions are heavily influenced by job location uncertainty due to job changes in the next period, as well as commuting uncertainty due to changes in commuting behaviours (Kan, 2022). Workers face uncertainty in their future jobs

(Kan, 2002), with key workers having lower rates of turnover and higher levels of employee loyalty (Lawson William, 2018). As a result, key workers have notably higher levels of certainty about their job location, yet most of the literature on residential location choices assumes that workers are certain about their jobs when deciding where to reside (Pérez et al., 2003; Marcucci et al., 2011; Guo & Bhat, 2001; Jiao & Harata, 2007; Srour et al., 2002). Notably, however, Crane (1996) did consider the effects of the uncertainty surrounding future job locations on commuting behaviour, and Parenti and Tealdi (2019) further developed the model by incorporating uncertain job locations and commuting costs. Yet even these researchers failed to provide empirical analysis and to investigate workers' choice of residential location when uncertain about job location. Multiple-worker households are much more common than single-worker households. However, these studies did not extend the model to the multiple-worker household. They did not consider the effects of commuting modes and work hours on commuting uncertainty or their influence on the choice of residential location.

To bridge all these gaps, this thesis offers a detailed estimate of the degree of spatial mismatch and the effect of housing affordability on spatial mismatch amongst key workers in Auckland. The degree of spatial mismatch was empirically quantified by constructing a spatial mismatch index at an area unit level. Beyond focusing on ethnicity, geography and skill sets, this thesis concentrates on spatial mismatch across occupations by theorising about and extending the testable implications of the hypothesis for occupational groups. This thesis also extends Alonso's (1964) land use theory by differentiating single-worker households and multiple-worker households, and it establishes a residential location choice model for the multiple-worker household. Besides, it offers an analysis of the residential location choices of multiple-worker households by considering job location uncertainty and differences in commuting costs.

Key workers' spatial distribution and the extent of their job–housing mismatch must be considered when attempting to ensure the smooth functioning of the urban services and the urban economy. Although many workers can indeed work from home, key workers such as healthcare workers, emergency services staff and those in community services roles must be physically present to provide their services and quickly respond to increased service demand during emergencies. An understanding of residential choice behaviour, particularly amongst multiple-worker households, is thus essential, with residential choice substantially influenced by the multiple-worker context. Because multiple-worker households act as a primary portion of the population seeking homeownership, evaluating their living preferences and analysing the factors that fundamentally affect their choice of where to reside can help the government better deliver affordable housing and devise welfare programs suitable for multiple-worker households.

This case study focuses on Auckland because it is one of the least affordable cities in the world (Hartwich, 2017). It is also one of the most representative metropolitan areas in New Zealand, accounting for 33.4% of New Zealand's total population. What's more, housing prices have risen by approximately 30% over the past five years, even as incomes have risen by only about half this rate in Auckland. Additionally, New Zealand's homeownership rate of 64.8% marks the least percentage of residents living in their own homes in 66 years. The situation in Auckland is particularly bad, with homeownership at less than 50% (Stats NZ, 2015). Fortunately, for the purposes of this research, Statistics New Zealand's micro-level Integrated Data Infrastructure (IDI) provides details about individuals' characteristics, including their residence and workplace, allowing individual-level analysis. Finally, unlike other world cities – such as London, New York or Melbourne – Auckland lacks a coherent policy framework for addressing key workers' housing needs.

The research objectives of this thesis are as follows:

1) Visualise the commuting patterns and identify the spatial distribution of select occupation groups.

2) Construct a distance matrix and spatial mismatch index, and test the effect of housing unaffordability on spatial mismatches of key workers and other occupations.

3) Model choice of residential location for multiple-worker households, estimating the effect of job location uncertainties and commuting uncertainties on multiple-worker households' decision about where to reside.

4) Recommend feasible policies for tackling spatial mismatch amongst key workers and assessing the housing needs of key workers in Auckland

1.3 Structure of the thesis

As Figure 1 illustrates, this thesis has been organised in the following chapters:

Chapter 2 gives an overview of the spatial distribution and commuting pattern of workers in Auckland. It uses the GIS framework and the Integrated Data Infrastructure (IDI) data at the individual level to visualise excess commuting flow among workers and examine the ways in which excess commuting is associated with deteriorating housing affordability.

Chapter 3 reviews the literature on residential location choices and spatial mismatch, with a focus on published academic journals and articles. The literature on residential location choices and residential choice under uncertainty is reviewed to offer perspective on the research topic. This chapter also draws attention to the mechanisms of spatial mismatch, spatial mismatch research involving key workers and spatial mismatch associated with commuting issues. The gaps in the literature on spatial mismatch for occupation groups and residential location choices under conditions of uncertainty are identified, with a conceptual framework formulated to guide the research.

The relevant analysis will then be unfolded and documented in the ensuing two chapters

Chapter 4 explores the relationship between spatial mismatch and housing affordability amongst key workers in Auckland. A distance matrix at an aggregate level and a spatial mismatch index are constructed to gain insights into the ways in which deteriorating housing affordability affects spatial mismatch amongst key workers. This chapter estimates the changes in key workers' constraints on residential location caused by housing affordability, describes empirical results and summarises findings while offering policy insights related to the worsening job–housing mismatch amongst key workers.

Chapter 5 focuses on renters' and multiple-worker households' choice of residential location. A two-workers, two-period, two-centre (2W×2P×2C) model of a linear city is developed to conceptualise how the (a) multiple commuters in a household, (b) job location uncertainties and (c) commuting costs affect the choice of residential location. Testable hypotheses are then developed, with linear regression estimation used to test them based on individual data. The end of the chapter summarises key findings and potential policy implications.

Chapter 6 provides an overview of the findings, then analyses the academic contribution of the current thesis, discussing its limitations and suggesting areas for future research while noting recommendations and implications.

STAGE OF RESEARCH	OBJECTIVE OF THE RESEARCH	STRUCTURE OF RESEARCH
AIMS AND OBJECTIVES	**OBJECTIVE 1** • To provide the background and motivation of the research • To propose the research questions • To introduce the thesis structure	**Chapter 1 Introduction** • Background • Aims and objectives • Structure of the thesis
STUDY ONE Identify the workers' spatial distributions Understand the workers' commuting patterns	**OBJECTIVE 2** • To provide the background of spatial distribution of selected occupation groups • To visualise the commuting patterns of workers	**Chapter 2 Commuting Patterns of Workers in New Zealand** • Integrated Data Infrastructure • Commuting pattern visualisation • Excess commuting
LITERATURE REVIEW Theories and concepts	**OBJECTIVE 3** • Review literature: spatial mismatch • Review literature: residential location choice	**Chapter 3 Theoretical Background** • Spatial mismatch • Residential location choice
STUDY TWO Aggregate-level quantitative analysis Housing unaffordability effect of key workers and other occupations	**OBJECTIVE 4** • To test housing unaffordability effect on spatial mismatch of key workers • To estimate spatial mismatch of different occupations affected by housing unaffordability	**Chapter 4 Spatial Mismatch and Housing Affordability of Key Worker** • Housing unaffordability effect on the spatial mismatch of key workers • Housing unaffordability effect on the spatial mismatch by occupations
STUDY THREE Individual-level quantitative analysis Distinguish residence choices for households of different compositions Identify the factors influence the residence locational choices for multiple-worker household	**OBJECTIVE 5** • To estimate residential location choices for different sizes of households • To examine the residential location choices under job location uncertainty • To test the residential location choices affected by commuting costs	**Chapter 5 Household Residential Location Choices under Uncertainty** • Single-worker households VS Multiple-worker households • Uncertainty of job location • Commuting modes • Work hours
CONCLUSION, LIMITATIONS AND FUTURE RESEARCH	**OBJECTIVE 6** • Study overview • To state the implication of the study • To examine the limitations of the research • To identify areas for future research	**Chapter 6 Conclusion** • Summary • Implications • Limitations • Future research

Figure 1 Structure of the thesis

Chapter 2

Commuting Patterns of Workers in New Zealand

Commuting behaviour has been intensively examined by geographers, urban planners, and transportation researchers, but little is known about how commuting behaviour is spatially linked with the job and housing markets in urban cities. New Zealand has been recognised as one of the countries having the most unaffordable housing over the past decade. A group of low- to moderate- class professionals called 'key workers', also known during the pandemic as 'essential workers', provide essential services for the community, but cannot afford to live near their workplaces due to a lack of affordable housing. As a result, these key workers incur significant sub-optimal commuting. Such job-housing imbalance has contributed to a so-called spatial mismatch problem. This chapter aims to visualise the excess commuting patterns of individual workers using the Integrated Data Infrastructure (IDI) from Statistics New Zealand. The visualisation suggests that over the last demi-decade, housing unaffordability has partially distorted the commuting patterns of key workers in Auckland. More of the working population, in particular those key workers, are displaced to the outer rings of the city. While there is an overall reduction in excess commuting across three groups of workers, key workers remain the working population with a disproportionate long excess commute.

2.1 Spatial distributions and commuting patterns

Commuting is crucial to enabling individuals to access job opportunities (Banister, 2005; Cropper & Gordon, 1991; Ta et al., 2017). Commuting patterns with shorter commuting distances and lower car dependency can generate significant positive externalities at both society level (e.g., lower carbon emissions) and individual level (e.g., lower commuting costs, and better quality of life). The urban economics literature argues that more accessible job opportunities close to workers' residences can reduce commuting costs and mitigate the spatial mismatch (Kain, 1968, 1992). Job-housing ratios at the district level are usually used to measure job-housing imbalance in an urban city, but many studies overlook the interactions of the commuting patterns of workers with the dynamics of housing affordability. Such a spatial mismatch is prominent amongst key workers.

There is no universal definition of ‘key worker’, with ‘essential worker’ and ‘frontline service provider’, for instance, being used interchangeably in various contexts. Often, key workers can be defined as the cohort of low- to moderate- income earners who work in the public sector and provide services that are essential to the functioning and livability of cities (Batty et al., 2021; Morrison, 2003; Steele & Todd, 2004). This definition includes low- to moderate- income public sector workers like teachers, healthcare and emergency service workers and other workers such as cleaners and delivery drivers. The term ‘key worker’ was first used in the United Kingdom to refer to workers who may find it challenging to secure homeownership in the area where they work. These workers usually earn too much to qualify for subsidised housing, but not enough to purchase housing at the market price. (Weaver, 2004). Many local public authorities in London have faced imminent problems retaining key workers due to a gap between lower income levels and access to affordable housing options in close proximity to their workplaces. In response to this predicament, the City of London has introduced various initiatives to attract key workers, including low-cost loans and shared ownership schemes. Under the early Key Worker Living programme, key workers were defined as national health service workers (including nurses, therapists and social workers, but excluding doctors and dentists); teachers; police; probation officers; educational psychologists, fire and rescue service staff and employees of local authorities and local education authorities (Airey & Wales, 2019). Nevertheless, even the national planning policy in England nowadays allows for considerable flexibility in how ‘key worker’ is interpreted in local policies. As Morrison (Morrison, 2013) explains, the term in Cambridge is extended to public sector workers in research and development, with housing for those workers considered essential to support the growth of the city with its research- and education-based economy. While the definition of key workers is location-specific, this study largely follows the convention in the related literature and defines key workers as health care workers, teachers, firefighters, and police in New Zealand.

Many researchers in urban studies addressed the issues of key workers (Morrison & Monk, 2006). Recent disruptions caused by the COVID-19 pandemic have highlighted the dependence of cities and their populations on these workers and have underscored the risks to resilience when those essential services are inadequately staffed, or the essential workers live significantly distant from the populations they serve. During the pandemic, while many workers could work from home during the national lockdowns, many key workers still needed to commute to their workplaces. The stress of commuting for key workers is high (Wilson, 2018). Many governments worldwide have also started to recognise the importance of providing essential services, and the workers in those corresponding sectors, e.g., health care workers and teachers. Key workers have a critical role to play in ensuring continued access to routine and essential services. In the spatial planning of a city, account must be taken of the public service workforce's significant contribution to the job-housing balance.

Two waves of micro-level household census data from the Integrated Data Infrastructure (IDI) compiled by Statistics New Zealand (Stats NZ) are utilised to analyse the excess commuting distance of key workers, finance-insurance workers, and retail workers in Auckland, the most populous city in the country. The findings suggest that the commuting of key workers is very sensitive to housing affordability. In both the 2013 and 2018 census years, key workers also exhibited the longest excess commutes, even though the overall commuting distances for various workers in 2018 were significantly (20%) lower than those in 2013. There is a disproportionate excess commute for key workers, albeit a declining average commuting distance across workers over the study period. This chapter aims to visualise the relationship between excess commuting and housing affordability, and emphasises that the commuting of key workers is more sensitive to housing costs compared to other working population. This is because key workers are often forced to relocate to outer suburbs and nearby regions to access affordable housing. Moreover, the excess commuting patterns reveal that key workers are generally displaced to the city fringe in Auckland. The long commuting problem of workers may also be manifested by the city perennial traffic problems (Mandic et al., 2020; Stroombergen et al., 2018).

The contribution of this chapter is threefold. First, to the best of our knowledge, the study in this chapter is an original attempt to analyse commuting patterns in the context of housing affordability from an occupational perspective. The excess commuting patterns provide evidence that key workers and retail trade workers are more sensitive to housing affordability than other workers. Second, this chapter analyses and visualises excess commuting distances by occupation. A novel way is proposed to estimate the commuting behaviours of workers; in addition, when worker commuting flows are mapped in terms of excess commuting distances, cluttering problems can also be alleviated. Third, this chapter develops a detailed data processing framework when handling the individual-level commuting data from micro-level datasets.

This chapter will be structured as follows: Section 2.2 provides a literature review on excess commuting and commuting flow visualisation. Section 2.3 introduces the data processing framework and presents the data and methodology. The results are discussed in Section 2.4. Section 2.5 presents conclusions.

2.2 Review the research on the spatial distribution

2.2.1 Commuting patterns visualisation

In the early research, many studies adopted a survey approach to unveil the commuting patterns, including time and distance (Deng et al., 2000; Li & Chai, 2000; Schwanen & Dijst, 2002). Chai (1999) conducted an activity survey and found an average 15 min commuting time in Lanzhou in 1992. Zhou and Yang (2005) developed a household survey and indicated a 40-minute commuting time in Guangzhou in 2011. However, their sample sizes were less than 1000, and because the commuting time was self-reported by respondents, bias was unavoidable. Some literature explores how commuting patterns reflect the connection between housing and the labour market (Coombes, 2010; Hincks, 2012). Ta et al. (2017) investigated changes over time in commuting patterns for 139 districts in Beijing and concluded that government intervention successfully achieved shorter commutes in China. Hincks & Wong (2010) used census aggregating flow data to investigate commuting in- and out-flows in North-West England. They pointed out that the commuting patterns enhanced their conceptual understanding of the housing/labour market interaction. However, they also indicated that the census data could not identify the factors that underpin commuting behaviour. Zhao et al. (2011) suggested that, due to market-oriented housing system reform in China, the higher the jobs-housing balance, the shorter the worker commuting time. Weber & Sultana (2008) utilised the transportation planning data in the 2000 census in the United States. They revealed that the workers who lived in sprawl areas had shorter commuting than those who lived in higher density areas when measuring commuting distance by using mileage. These results are consistent with other studies indicating that workers in sprawling areas may have less commuting times (Crane & Chatman, 2002).

With the availability of big data, recent studies have begun to explore commuting patterns by using a plethora of data generated from public facilities, such as footprint data, smart card data, and mobile phone data (Chen et al., 2011; Ma et al., 2017; Toqué et al., 2016; Wu et al., 2019; Yeghikyan et al., 2020). Zhou et al. (2014) measured commuting efficiency in Beijing using smart card data and found that workers who used public transport modes had shorter commuting times than workers who used private transport. Ma et al. (2017) analysed spatial-temporal commuting patterns of workers, again using smart card data, and showed the job-housing imbalance in Beijing. Yang et al. (2018) applied mobile phone data to identify the commuting convergence and divergence for each community and visualised the commuting network pattern. Indeed, big data nowadays provides us with opportunities to study commuting patterns more thoroughly. For example, Batty et al. (2021) visualise the workplace distribution and residence distribution using census-tract level data. However, the census data they used is still at an aggregate level and the analysis cannot identify individuals' characteristics such as their occupations. To the best of our knowledge, there is limited literature investigating commuting patterns by occupation (Batty et al., 2021). So far as we are concerned, none of the previous studies has observed worker commuting patterns by occupations with census data at such a granular level.

2.2.2 The origin-destination flow map

Apart from investigating commuting behaviours and measuring the commuting distance, a commuting map also helps us understand commuting patterns (Zhou et al., 2019). A flow map is a typical way of visualising the work-to-home journey, and it has a wide range of applications such as transportation flow and commuting flow (Dong et al., 2018; Guo, 2009;

Lu et al., 2016; Ni et al., 2017; Rowe & Patias, 2020; Sakamanee et al., 2020). Tobler (1987) presented some early examples of the initial flow map to show geographical movements. Rae (2009) indicated that flow map functionality has remained underdeveloped and summarised how some of these techniques could be implemented in sizeable geo-information visualisations. Visualising commuting flow patterns has become a critical issue for urban planning and transportation management (Ta et al., 2017; Vale et al., 2018; Acker & Witlox, 2011). Origin–destination (OD) flow maps show origin and destination nodes on a geographic map. Such maps can be classified into three main categories in terms of the estimation methods used: survey-based methods, traffic counts-based methods, and positioning technology-based methods (Yang et al., 2015). Möller et al. (2018) demonstrated cross-border commuting flow by conducting a survey and found that cross-border commuting shared common features with intra-national commuting. Nevertheless, survey-based OD estimation is usually limited by sample size and selection bias. Zhang et al. (2017) and Watson & Prevedouros (2006) used the link traffic count of traffic detectors from a transportation company to simulate the real traffic network.

Nevertheless, visualising commuting flow using traffic counts requires extensive data; the corresponding metering infrastructures must be available in the relevant research area (Yang et al., 2015). Kreindler & Miyauchi (2021) mapped commuting flows using call detail records from the individual cell phone data. The study tried to identify the cell tower locations according to phone-related activities such as outgoing or incoming voice call and text and demonstrate the spatial distribution of workers in Dhaka, Bangladesh and Colombo, Sri Lanka (Kreindler & Miyauchi, 2021). However, such locational-based data will not consider the individual level demographic features. Although OD flow maps have been widely used in delineating commuting flows, they suffer from several challenges, such as the visual clustering problem, modifiable area unit problem, and the problem of normalisation process (Guo & Zhu, 2014). Andrienko & Andrienko (2010) suggested that aggregating locations into large regions could simplify mapping flows. To reduce the number of OD flow lines, Guo (2009) and Rae (2009) used sampling and showed only a subset of data. However, both the aggregation and the sampling methods will inevitably result in the loss of information.

2.2.3 Excess commuting

The commuting distance has to be compared with the average commuting distance within the corresponding metropolitan area; or otherwise, such comparison is not like-with-like and could be misleading. Such a benchmarking concept is intended to depict "the extent to which areal units inhabited by minority members adjoin one another, or cluster, in space" (Massey & Denton, 1993). In this study, the excess commuting distance measures are intended to compare the change in a particular population group with the overall population change. Hamilton & Röell (1982) introduced the concept of "wasteful commuting" that measures sub-optimal excess commuting based on the classical monocentric urban model (Alonso, 1964; Mills, 1967; Muth, 1969). Many research works discuss excess commuting in the United States (Cropper & Gordon, 1991; Hamilton, 1989; Small & Song, 1992). White (1988b) indicated that excess commuting referred to sub-optimal commuting time or distance resulting from the imbalance of the residences and workplaces within a city. Giménez et al. (2015) analysed excess commuting for the self-employed versus the employed and found that employees commuted for twelve more minutes per day. Ha et al. (2018) utilised multi-dimensional indices to examine the excess commuting in 206 metropolitan areas of the United States. They revealed that a highly centralised city would reduce the excess commuting of workers. Bwire & Zengo (2020) investigated excess commuting in Dar es Salaam and suggested that both public and private transport help provide work-to-home trips. They also concluded that the commuting situation in developing countries is very different from that in developed countries. Park & Chang (2019) showed that transit supply and job-housing balance were two primary factors contributing to excess commuting in Seoul. The current urban planning for light-rail construction cannot alleviate the spatial inequality of excess commuting in the city.

Research on excess commuting has focused on two key areas. One is the interpretation of excess commuting through the construction of relevant indicators. Horner (2002) utilised census transportation planning data to establish an excess commuting index and found that excess commuting in metropolitan areas ranged from 46.75% in Charlotte to 67.21% in Philadelphia. Murphy & Killen (2011) introduced two new methods to measure commuting efficiency using the excess commuting framework. They implied that the greater the mix of residential and employment functions, the more efficient the commuting of workers would be. O'Kelly & Niedzielski (2008) combine excess commuting with the constrained spatial interaction model to show how average commuting could be reduced. Another key area of study of excess commuting is the policy implications associated with the concept. Merriman et al. (1995) measured the excess commuting of 211 OD points in the Tokyo metropolitan area. They found that 90 per cent of commuting was "excessive" (i.e., sub-optimal) in Tokyo and suggested that both decentralising jobs and centralising workers could significantly reduce excess commuting. Some literature considered the relationship between job-housing and excess commuting (Kim, 1995; O'Kelly & Lee, 2005). Frost et al. (1998) implied that urban structure change would exacerbate excess commuting.

This chapter visualises excess commuting flows by utilising individual-level residence and workplace geography data. On the one hand, the excess commuting flow map demonstrates the spatial distribution and commuting patterns of workers. This is a like-with-like comparison because excess commuting always refers to the average commuting of a particular worker group. On the other hand, excess commuting flow maps can reduce the OD flow lines and alleviate the visual cluttering problem without the loss of any critical information.

2.3 Visualisation methods

2.3.1 Integrated Data Infrastructure and the data processing

Integrated Data Infrastructure (IDI) is a micro-level dataset about people and households compiled by Statistics New Zealand (Stats NZ) for non-government organisations (NGOs) and academics to gain scientific insight into social issues. The IDI contains person-centred microdata from a wide range of government agencies, surveys, and NGOs (Stats NZ, 2021b). The data can be categorised into eight data categories. The residence meshblock and workplace meshblock were employed as the origin and destination proxy when calculating the commuting distance. This chapter applies the data from the categories of "people and communities" and "population" to derive the commuting flow of individual workers. These two datasets are generated from the census survey that runs every five years in New Zealand. In this chapter, the commuting flow of workers is calculated based on the commuting distance between centroids of the residence meshblock and workplace meshblock in the census year of 2013 and 2018. A meshblock is the smallest geographic unit in which the statistical data is reported by Stats NZ (Stats NZ, 2021a), similarly to the Census tracts in the United States. There are no more than 120 dwellings within a meshblock.

Figure 2 shows the distribution of meshblocks in Auckland in 2018, the most populous city of New Zealand, which has 1.657 million populations and accounts for 35% of the total population in New Zealand. In Auckland, there were 11,768 meshblocks in 2013 and 13,736 meshblocks in 2018.

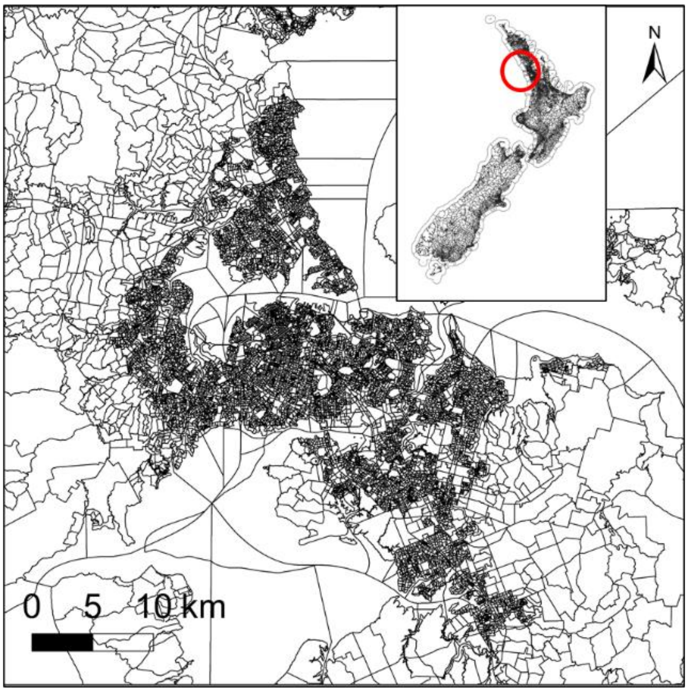


Figure 2 Distribution of meshblocks in Auckland in 2018

Table 1 shows the sample size of the selected worker groups and meshblocks. There were 203,055 key workers in 2013 and 253,542 key workers in 2018. Two comparisons (non-key workers) groups, including finance-insurance and retail trade workers, are introduced. Compared with non-key workers, key workers have a relatively lower turnover rate and work for a particular institution such as hospitals and schools for a more extended period (Lawson Williams, 2018). Thus, because key workers are unlikely to change their workplaces due to the permanency of their employment, they are more sensitive to changes in housing affordability.

Table 1 Census sample size

	Occupation Classification	Occupation Code (first three-digit)	2013	2018
Key workers	School Teachers	241	77,580	94,509
	Nursing	254	41,379	51,591
	Health Workers	411	18,228	29,229
	Child Carers	421	8,667	10,548
	Personal Carers	423	41,337	48,663
	Fire Fighters and Police	441	15,864	19,002
Total			203,055	253,542
Finance-Insurance workers	Accountants and Auditors	221	28,143	33,999
	Financial Brokers and Dealers	222	10,473	12,507
	Insurance Agents	611	43,533	55,476
Total			82,149	101,982
Retail Trade workers	Salespersons	621	96,834	125,313
	Sales Support Workers	639	8,172	9,009
	Storepersons	741	17,814	26,610
Total			122,820	160,932
Meshblock Residence			40,612	47,199
Meshblock Workplace			27,554	33,378
Paired Meshblock			318,397	338,957

Notes: The IDI of Statistic New Zealand provides the meshblock codes and area unit codes of residence and workplace of each individual with their x-y coordinates and occupation codes. Key workers group, finance-insurance workers, and retail trade workers report 40,612 residence meshblocks and 27,554 workplace meshblocks in 2013, and they report 47,199 residence meshblocks and 33,378 workplace meshblocks in 2018. 318,397 paired origin (residence meshblock) – destination (workplace meshblock) flows are found in 2013 while 338,957 paired OD flows were found in 2018. Those meshblock flows can aggregate to 85,320 area unit flow in 2013 and 83,160 area unit flow in 2018.

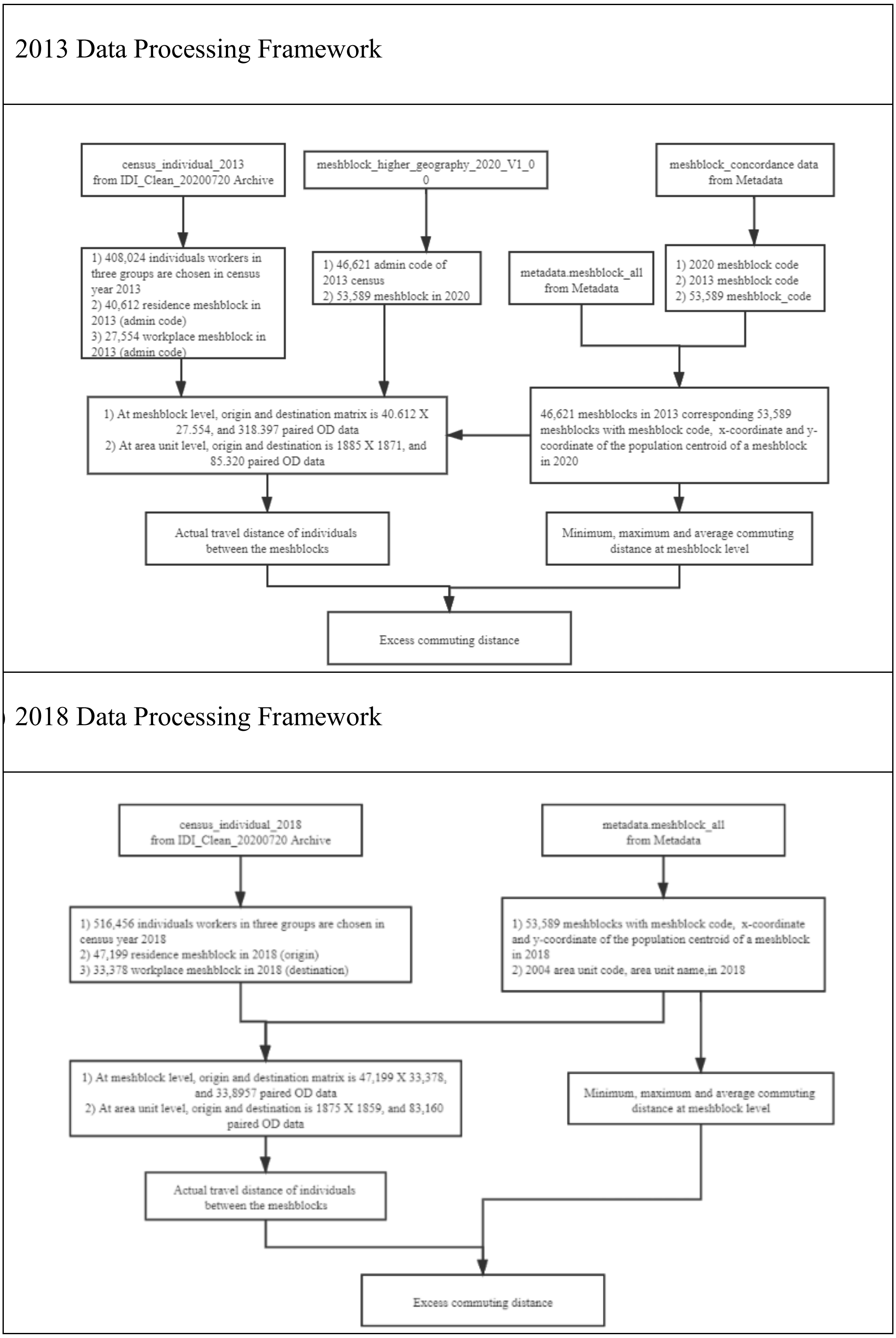


Figure 3 Excess commuting data process[1] framework by using IDI data

[1] The details of matching the meshblocks have been described in Appendix 4

Figure 3 (a) and Figure 3 (b) summarise the data processing within the IDI in 2013 and 2018, respectively. Figure 3 (a) demonstrates the data processing procedure for the census year 2013. From the individual data in the census, the admin codes of meshblocks in 2013 are obtained, and their centroid coordinates are sourced from the concordance metadata. From the datasets, we can calculate each worker's commuting distance and their excess commuting distance relative to the average commuting distance of the workers living in the same meshblock. Similarly, Figure 3 (b) shows the data processing for the census year 2018. Individual census data and meshblock metadata are employed to collect the residence, workplace meshblock, and corresponding x-y coordinates. The coordinates are used to calculate workers' commuting distance and excess commuting for 2018.

2.3.2 Housing affordability

This chapter utilises the modified median multiple (housing costs relative to income) as the proxy of housing affordability. Median Multiple is widely used to evaluate urban markets, and has been recommended by the World Bank and United Nations, as well as the Harvard University Joint Center on Housing (United National, 2004; JCHS, 2017; World Bank, 2019; OECD, 2022). Urban Reform Institute and Frontier Centre for Public Policy conduct the international housing affordability survey and present the housing affordability report worldwide every year from 2005 (Demographia, 2021). In general, the median multiple denotes a ratio of the median house price to the median annual income. In addition to providing meaningful and transparent comparisons of housing affordability, the Median Multiple is a reliable, easily understood and useful indicator of the health of residential markets.

However, the indicator is sometimes criticised for being oversimplified in measuring housing affordability without taking into account the actual housing costs, especially mortgage expenses. Therefore, in this section, the mortgage rates and loan-to-value (LTV) ratios in different census years are used in lieu of the simple median multiple. The formula of our modified median multiple is as follows:

$$Housing\ Unaffordability_{at} = \frac{Hc_{at}}{income_{at}} \quad (1)$$

$$HC_{at} = \overline{pmt_{mt}}\ (rate_t, 30, median\ price \times LTV_t) \quad (2)$$

where $Housing\ Unaffordability_{at}$ is the measurement of unaffordability of the housing at area unit *a,* in census year *t*; HC_{at} denotes the housing costs of area unit *a*, in census year *t*, while the *income* at is the average annual income of workers living in area unit *a* in census year *t*. To measure housing costs, mortgage repayment is used. $\overline{pmt_{mt}}$ represents the mean mortgage repayment of meshblocks in an area unit. The numbers 0.050 and 0.057 are used as new two-year residential mortgage interest rates for 2013 and 2018, respectively, and 90% as an LTV ratio to calculate the mortgage repayment of each area unit in 2018. Therefore, the ratio measures the housing unaffordability of a location. The higher the value of *Housing Unaffordability*, the less affordable the location is.

This thesis utilises the adjusted housing unaffordability measure by considering the different interest rates and loan-to-value ratios over the years. And the 3.0 standard has been applied in measuring the magnitude of housing unaffordability. The report presented by Demographia has shown that the median multiple indicator was at or below 3.0 in Australia, Canada, Ireland, New Zealand, the United Kingdom and the United States until the late 1980s or late 1990s (Demographia, 2021). This historic affordability relationship of a median multiple in the range of from 2.0 to 3.0, with 3.0 as the outer bound of affordability continues in many housing markets, including New Zealand (Demographia, 2021). Grimes (2016) emphasised the 3.0 standard in housing affordability research in New Zealand. The Ministry of Business Innovation and Employment of New Zealand also noted the median multiple methods and 3.0 standard in measuring housing affordability of New Zealand (Kerr and Robertson, 2017). To keep the consistency of median multiple standards, the standard of adjusted housing unaffordability measures ranks 0.3 and below as affordable, indicating that the household pays 30% or less of their income for mortgage repayment regarded as affordable; the adjusted housing unaffordability measures ranks 0.31 to 0.4 as moderately unaffordable, meaning that the moderately unaffordable suggests the household pays 31% to 40% of their income for mortgage repayment; the adjusted housing unaffordability measures ranks 0.41 to 0.5 implies that the household pays 41% to 50% of their income for mortgage repayment and will be regarded as seriously unaffordable; while the adjusted housing unaffordability measures ranks 0.51 or above suggests that more than half of the household's income is used to pay for the mortgage repayment and ranks as severely unaffordable.

Table 2 presents a summary of the housing affordability of different regions in Auckland. It is intriguing to note that housing affordability in 2018 and 2013 have a significant difference. Housing unaffordability for 2018 is generally more severe than that in 2013. This indicates that housing affordability in all regions of Auckland has deteriorated between 2013 and 2018. Additionally, housing in Western and Southern Auckland is much more affordable, as manifested by the two lowest housing affordability measures in these regions. In 2013, Central Auckland was the most unaffordable region, followed by the Eastern and Northern regions, while in 2018, the Eastern region was the most unaffordable region, followed by the Central and Northern regions. Apart from the median housing affordability, the minimum and maximum housing affordability vary significantly in Central and Southern Auckland in 2013 and 2018. This indicates that housing affordability is quite diverse across different submarkets.

Table 2 Summary of housing affordability in Auckland

	2013			2018		
Region	min	median	max	min	median	max
Northern	0.77	1.227	2.421	0.649	1.261	3.69
Western	0.775	1.031	1.306	0.854	1.052	1.375
Central	0.308	1.401	3.438	0.216	1.409	2.796
Eastern	0.723	1.394	2.108	1.044	1.482	2.296
Southern	0.384	1.006	3.638	0.338	1.069	22.783

2.3.3 Excess commuting distance

In essence, estimating excess commuting distances involves two stages of analysis: 1) calculating the actual commuting distance of individuals; and 2) measuring the average commuting distance of particular types of workers who live in the same meshblock. For the first stage, we calculate the actual commuting distance of individuals by using the residence meshblock (*r*), workplace meshblock (*w*), and their corresponding x-y coordinates:

$$D_{it} = D_{rwt} \tag{3}$$

$$D_{arot} = \frac{1}{N_{ot}} \sum D_{ort} \tag{4}$$

Equation (3) shows the commuting distance between the residence and workplace meshblock of individuals *i* at census year *t*. Equation (4) shows the average commuting distance of one type of workers who live in the same meshblock, where *o* represents the occupation groups. The occupation types belong to key workers, finance and insurance workers, and retail trade workers. The occupation types include 11 occupations which are listed in Table 1. They are school teachers, nursing, health workers, child carers, personal carers, fire fighters and police, accountants and auditors, financial brokers and dealers, insurance agents, sales persons, sales support workers, store persons. Thus, D_{arot} denotes the average commuting distance of workers, who work as *o* occupation at census year *t*. $\sum D_{ort}$ sums up the commuting distance of workers who are *o* occupation and live in *r* meshblock at census year *t*.

$$\begin{cases} D_{iet} = D_{it} - D_{arot} > 0, & D_{it} - D_{aot} \\ D_{iet} = D_{it} - D_{arot} < 0, & 0 \end{cases} \quad (5)$$

Equation (5) is employed to determine whether the worker has excess commuting during daily commuting, and further visualises the excess commuting flows. D_{it} denotes the actual commuting distance of the worker at census year *t* and obtained from Equation (3), whereas D_{arot} represents the average commuting distance of workers who are in *o* occupation and live in *r* meshblock at census year *t*, where D_{iet} denotes the excess commuting distance of worker at census year *t* if D_{iet} is larger than zero, and D_{iet} equals zero if D_{iet} is smaller than zero. In addition, the visualisation focuses on the situation when workers have extra commuting. If D_{iet} is smaller than zero, D_{iet} equals zero suggests that the commuting flow will not be displayed in the map. If D_{iet} is larger than zero, D_{iet} measures the extra commuting of the workers compared with the other workers who are in the same occupation and live in the same area unit. The larger the value of D_{iet}, the longer the excess commuting distance, the worse the magnitude of the spatial mismatch of workers who are *o* occupation and live in r meshblock. On the one hand, the visualisation will be more clear as not all commuting patterns will be displayed on the map; on the other hand, the length of the commuting flow line denotes the extent of the spatial mismatch.

2.4 Visualisation of excess commuting patterns

2.4.1 Excess commuting results for 2013 and 2018

Table 3 presents the commuting flow analyses in 2013 and 2018 for key workers, retail trade workers, and finance-insurance workers. The results show that in 2013, the average commuting distances were 16.61 km, 15.19 km, and 15.53 km for key workers (KEY), retail trade (RET) workers, and finance-insurance workers (FIN), respectively. Evidently, key workers exhibit longer commuting as compared to retail and finance-insurance workers. The minimum commuting distances are zero across three groups as workers can work and live in the same meshblock. The maximum commuting distance is 871.49 km for key workers and 387.91 km for finance-insurance workers, suggesting that there could be “mega-commuters” in these two worker groups. The average excess commuting distances for key workers, retail trade workers, and finance-insurance workers, respectively, are 8.80 km, 7.64 km, and 8.07 km, respectively. These results imply that the key workers usually commute further than the other two groups.

Table 3 Commuting distance pattern by occupation in 2013 and 2018

Occupation	Commuting distance (km)			Excess commuting (km)	Excess commuting (%)
2013	Mean	Min	Max	Mean	%
KEY workers	16.61	0	871.49	8.8	28.08%
RET workers	15.19	0	51.39	7.64	24.10%
FIN workers	15.53	0	387.91	8.07	25.80%
2018	Mean	Min	Max	Mean	%
KEY workers	13.5	0	561.64	6.1	31.35%
RET workers	12.33	0	59.88	5.98	26.97%
FIN workers	12.44	0	525.09	5.87	29.74%

Note: The distances are all the direct distance between the residence and centroid of workplace meshblock.

Apart from the average commuting distance and average excess commuting distance, Table 3 also shows the percentage of the population who suffers excess commuting among each group of workers. The statistics indicate that the percentages of the excess commuting population for KEY workers, RET workers, and FIN workers are 28.08%, 24.10%, and 25.80%, respectively. This finding suggests that across the three worker groups, key workers suffer the most in terms of excess commuting. Comparing workers in each group, key workers have a higher proportion of workers who suffer excess commuting, whereas fewer finance workers and retail trade workers require excess commuting.

Indeed, in our analysis, it is worth noting that both average commuting distance and excess commuting distance have been reduced from 2013 to 2018 across all occupations. The shorter commutes imply that there is a decentralisation of job locations. Together with implementing the Auckland Integrated Fare System (AIFS), a smartcard ticketing system that can be used on trains, ferries, and buses since 2011, many infrastructures, such as the electric train service in Eastern and Southern Auckland, were also developed. The construction of Eastern Busway, Manukau and Pah Roads transit lanes and the upgrade of Glenfield Road and Neilson Street altogether improved worker commuting from 2013 to 2018 (*Projects & Roadworks*, n.d.). Our results suggest that Western Auckland and far Northern and Southern Auckland could be the targeted areas to further develop such infrastructures.

While the results imply an overall reduction in both absolute and excess commuting distance across three groups of workers, key workers are still the group with the disproportionately longest commute among worker groups. The statistics strongly shows that although the absolute commuting distance has been lessened for various workers from 2013 to 2018, key workers are either the most sensitive to deteriorating housing affordability or the most adversely affected by job-housing imbalance.

2.4.2 Housing affordability in Auckland

Figure 4 illustrates the Auckland Region's housing affordability in two census years. Both in 2013 and 2018, the deep red coloured areas such as those in Central and Northern Auckland are the least affordable while the purple shaded areas, including Western and Southern Auckland, are the most affordable. The heat map of housing affordability shows that parts of Eastern Auckland became less affordable in 2018. Furthermore, Figure 4 demonstrates that housing affordability deteriorated from 2013 to 2018 since red coloured areas increased in 2018 and the unaffordable areas expanded to Auckland's outer suburbs.

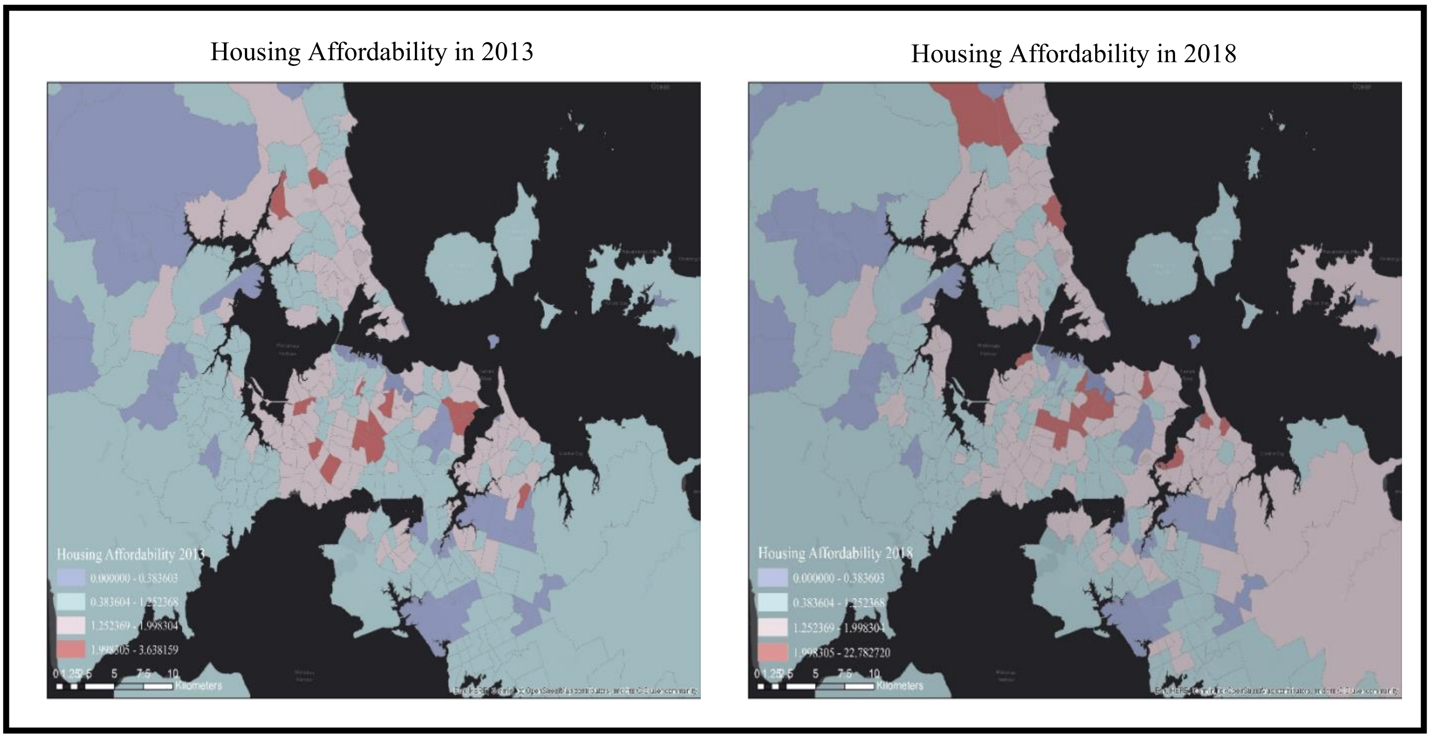


Figure 4 Housing affordability in Auckland

2.4.3 Excess commuting patterns

Figure 5 illustrates the excess commuting flows for three groups of workers in the census years 2013 and 2018. The blue commute flow lines denote an excess commuting distance shorter than 1.16 km, whereas the green line denotes an excess commuting distance between 1.16 km to 3.53 km. The purple flow line denotes an excess commuting distance longer than 3.53 km[2].

Figure 5 a–c present the excess commuting flows of key workers, retail trade workers, and finance workers in 2013, respectively. As shown in Figure 5 a, the commuting flow lines

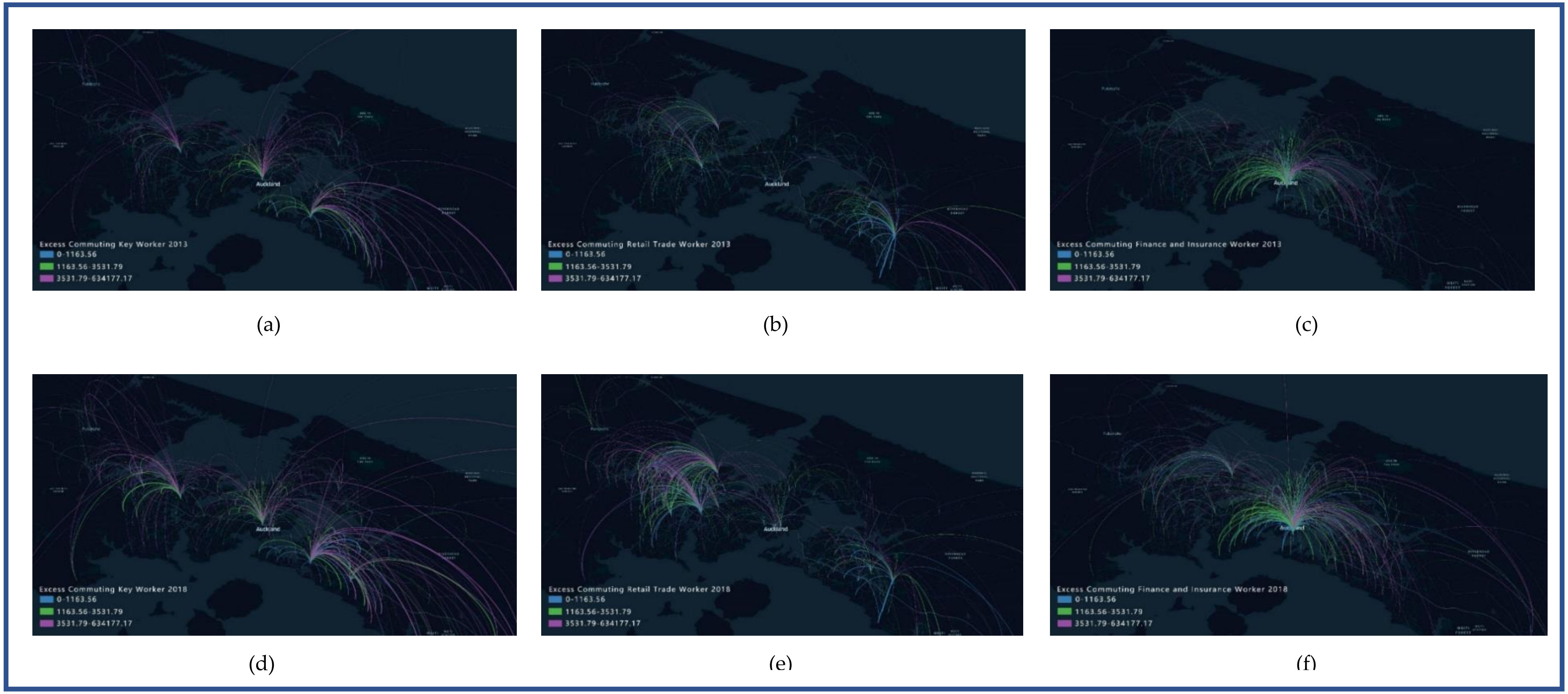
[2] 1.16 km is the 25 percent tile of excess commuting distance of key workers in 2013, while 3.53 km is the 50 percentile of excess commuting distance of key workers in 2013.

of key workers are dominated by purple coloured lines. The visualised commuting flow suggests that key workers have a relatively longer excess commuting distance and radiate to the fringe of North, South, and Western Auckland. Figure 5 b presents the excess commuting flows for the retail trade workers. The blue coloured commuting flow predominates South Auckland, while Central and North Auckland have much green commuting flow strewn around the map. This implies that retail trade workers in South Auckland have relatively minor excess commuting, whereas the magnitude of excess commuting of retail trade workers in North and Central Auckland is slightly more severe. Besides, the less prevalent excess commuting flows for retail trade workers in Central Auckland suggests that the majority of these workers have moderate commuting distances, and can either find a job near their residence or have a sufficient supply of job opportunities. Figure 5 c shows the excess commuting flows for finance workers. The commuting pattern indicates that finance workers are more concentrated in the inner city where most banks are located. Most green coloured commuting flows for finance insurance workers are situated between Central and South Auckland, implying that those living in South Auckland require an excess commute to work.

Likewise, Figure 5 d-f show the excess commuting flows of the three working groups in 2018. Figure 5 d describes the excess commuting flow of key workers, and the purple lines again take over the excess commuting flow in North, South, and Central Auckland. Compared with the map of 2013, there is a noticeable increase in the purple line of key workers and new occurrences of green lines in North and Central Auckland. In addition, more purple lines extend to the city fringe. The visualisation reveals that the magnitude of excess commuting is exacerbated in South and North Auckland over the years. The excess commuting distance of most key workers is more than 3.5 km. Figure 5 e shows an excess commuting pattern for retail trade workers and less extensive (green coloured) flows concentrated in South and North Auckland. The pattern implies that many retail trade workers who commute in South and North

Auckland have an excess commuting distance of around 1.16 km to 3.53 km. In comparison with the patterns of retail trade workers in 2013, the excess commuting has diminished in South Auckland while worsening in North Auckland.

Figure 5 f illustrates the excess commuting flows of finance-insurance workers in 2018, and their excess commuting pattern is similar to the pattern in 2013, which is concentrated in the inner city. Many finance-insurance workers who suffer excess commuting longer than 3.53 km are commuting between Central and Eastern Auckland. Moreover, there is a significant increase of excess commuting between Western and North Auckland among finance workers, and the excess commuting to South Auckland is dispersed to the outer ring.



Notes: (a) excess commuting of key works in 2013; (b) excess commuting of retail trade workers in 2013; (c) excess commuting of finance and insurance workers in 2013; (d) excess commuting of key works in 2018; (e) excess commuting of retail trade workers in 2018; (f) excess commuting of finance and insurance workers in 2018. The flow diagram is also available online, retrieved from https://ibb.co/jbT4nLv. To maintain privacy, confidentiality, and data security, Stats NZ will suppress the information from IDI (remove its value) when it releases its data outputs. Thus, we can only use the commuting data of the meshblocks with more than six workers living in a meshblock. The detailed microdata output guide can be retrieved from https://www.stats.govt.nz/assets/Uploads/Integrated-data-infrastructure/microdata-output-guide-fourth-edition.pdf

Figure 5 Excess commuting patterns in 2013 and 2018

2.5 Remarks on excess commuting patterns

2.5.1 Linking housing affordability and excess commuting patterns

As manifested by the housing affordability patterns in Figure 4 and the excess commuting patterns in Figure 5, the excess commuting flow lines became more intensive over the years, regardless of occupation. This implies that the problem of excess commuting is exacerbated. Considering the housing affordability and excess commuting patterns in Auckland over the years, the key workers are the most sensitive to the dynamic of housing affordability, with more deep red coloured areas following the purple coloured commuting flow lines of key workers. The fact that more intensive excess commuting flows of key workers extend to the outer ring of North and South Auckland indicates a severe job-housing imbalance in those areas. In other words, key workers are either unable to find a job near their residence or find it impossible to afford housing near their workplace. As a result, they are leaving Central Auckland and have to undergo excessive commuting.

Interestingly, even though Central Auckland has the most severe housing affordability, the excess commuting of retail workers did not find much concentration, especially in 2013. This means that only a few retail workers in Central Auckland experience excess commuting, and the job-housing balance of retail trade workers is relatively better than that of workers in other occupations. The moderate commuting of retail workers in Central Auckland also translates into sufficient retail trade job opportunities in Central Auckland. Not only are there a variety of part-time and full-time options in Central Auckland, but also there was 52.10% in 2013, while 55.81% in 2018 of retail trade workers were renters. As a result, they have more options in choosing their living and working places. Finance workers are the least sensitive to the housing affordability change since the excess commuting pattern of finance workers radiates from Central Auckland in all directions, regardless of where the unaffordable housing areas are.

2.5.2 Limitations and future work

Despite the contribution discussed, several limitations exist in the current chapter, mainly due to the strict confidentiality rules for the census data and the limited access to the GIS-related software in the IDI DataLab environment. Due to the protection of personal information, IDI DataLab did not allow researchers to map the road networks to individual addresses. As such, this chapter can utilise only Euclidean distances as the second-best solution to estimate commuting distances. While some studies using OD cost distance in Auckland (Australasian Railway Association, 2015; Badland et al., 2007; Goodyear, 2008; Mattingly & Morrissey, 2014) have indeed documented the commuting patterns, e.g., Goodyear (2008) and Badland et al. (2007), their analyses to estimate the commuting distance and time are limited to survey samples. To overcome the limitations of using absolute commuting distance, this chapter examines the magnitude of "excess" commuting of workers within the same occupation group who live in the same areas and compares their commuting flow and spatial distribution across multiple occupation groups. Our research provides compelling insights into visualising the commuting flows of different occupation groups in Auckland. The visualisation depicts different patterns of worker mobility of various occupations, as well as corresponding spatial distributions of diverse occupations over the years in the Auckland Region. In addition, the average commuting distances can also be compared with the New Zealand Household Travel Survey estimates (Statistics NZ, 2014) studies that investigated the relationship between the housing market and commuting. The concept of "excess commuting" may not be groundbreaking in urban studies (Giménez et al., 2015; Mills, 1967; Muth, 1969; White, 1988b). However, the application of excess commuting is rather primitive and confined to measuring job–housing imbalance. Using the concept of excess commuting to improve the measurement of OD seems to be overlooked in the relevant literature, and particularly neglected by geo-information researchers. First, future research could visualise excess commuting by renters and homeowners across employment groups since renters are more flexible in choosing a residence. Second, researchers can depict the actual commuting flow and benchmark the efficiency of different types of visualisations. Third, the concept of excess commuting can also enrich the measurement of excess commuting through granular-level data. Thus far, limited geo-information studies have explored the commuting patterns and spatial distributions of workers by occupation in Auckland (Ralphs & Goodyear, 2008). While Ralphs & Goodyear (2008) visualised the commuting flow of all workers in New Zealand at the city level, they failed to demonstrate the degree of deterioration of commuting and of the spatial distribution of workers within a specific city. Future studies could investigate the dynamic of working population mobility by estimating the excess commuting in Auckland longitudinally or by examining policies for alleviating the magnitude of excess commuting and job-housing imbalance.

2.5.3 Conclusion

Many studies have addressed the methodological framework for measuring excess commuting and analysing spatial distribution with commuting (Charron, 2007; Horner, 2002; Ma & Banister, 2007; Stats NZ, 2014; Ralphs & Goodyear, 2008). This chapter utilises the GIS framework and the IDI data at the individual level to examine how excess commuting is associated with deteriorating housing affordability. The use of spatial information in the IDI data is novel, and the methodology of visualising excess commuting is also an innovative way to present commuting flows. The visualisation in this chapter suggests that although the overall commuting distance and excess commuting steadily reduced from the year 2013 to 2018 due to either the decentralisation of job opportunities and/or the improvement of public transportation, key workers who usually work in a fixed location continue to suffer the longest commutes and exhibit disproportionate excess commuting relative to other workers. Compared to the other two major groups of workers in Auckland, constrained by budget key workers are making sub-optimal housing choices living further away from where they work and accepting longer commutes.

To the best of my knowledge, few studies are examining excess commuting from an occupation perspective. Theoretically, this chapter fills the research gap in commuting literature by considering the roles of occupations in the context of commuting patterns and spatial distributions. The excess origin-destination (OD) flow model, estimating average commuting distances and average excess commuting distances, shows that the commuting flow patterns vary by occupation. Moreover, this chapter shows that key workers suffer the lengthiest commutes and have the longest excess commuting despite the reduced commutes across other worker groups. It is due to the fact that there is an increasing trend of key workers living in the outer ring of the Auckland Region and residing much more dispersed.

Practically, this chapter introduces a novel concept of using excess commuting flows in visualising the conventional presentation of commuting flows. The proposed method also represents a new approach to alleviating the cluttering problem when visualising the commute flow maps at an individual level. First, using excess commuting flow rather than actual commuting flow can streamline the flow lines on the map without missing the crucial information from the raw data. Such "excess commuting flow" visualisation can be applied to urban studies on commute flows in the future. Second, by quantifying excess commute in different occupations, policymakers can be better informed to formulate a city structure that assuages excess commute. Creating more affordable houses nearby job centres and decentralising workplaces to make the job centres more accessible is always the key to alleviating the excess commuting issue, no matter in New Zealand or elsewhere in the world.

Chapter 3

Theoretical Background

This chapter provides a literature review on residential location choices. The first section provides a background of the development of residential location choices. The second section will discuss the factors contributing to a household's residential location choices and what constrains households when they make those decisions. Then, the spatial mismatch resulting from the sub-optimal residential location choices will be analysed in the third section. Last but not least, the mechanism of spatial mismatch will be discussed, which would help address why constrained residential location choices matter in the urban spatial distribution. After carrying out a thorough literature review, the last section will identify the research gaps to be bridged in this thesis.

3.1 Literature on residential location choices

3.1.1 Residential location modelling: a theoretical perspective

Why people prefer to live in a specific location is a central question in urban studies. In the early nineteenth century, Von Thünen (1826) recognised the effects of transportation costs on production activities and the function of the land market in an agricultural society where landowners are willing to rent their properties to the highest bidder, in which the concept of the bid-rent theory started to emerge. This also provides the background for residential location choices modelling later on. By applying the single-market structure and the bid-rent model concept, Alonso (1964), Mills (1967), and Muth (1969) developed a monocentric city model. They offer the first attempt to encapsulate city transport, land use, and population issues in a monocentric city model. The seminal work of Alonso (1964) also introduced the budget consideration when households choose where to live, and he proposed that households decide their residence based on a utility function that depends on the size of the land, the distance to the city centre, and the expenditure on goods. At the same time, Lowry (1964) applied the gravity model to study residential locations. Lowry assumes an initial set of primary employment centres. Households are allocated to a specific location, i.e., zone, based on a deterrence function that describes the number of workers employed and living in a zone.

With the discrete choice model framework introduced by McFadden (1978), many studies hereafter started to examine residential location choices. Research initially focused on households that moved within a certain geographic area, referred to as a zone (Anas, 1982; Weisbrod et al., 1980). Each zone has its own characteristics, such as housing prices, employment level, crime rate and accessibility to other zones. Households choose the location to maximise their utility, while prices are determined exogenously at a given price. The discrete choice modelling is capable of quantifying various residential locational characteristics and their dynamics with household characteristics. With the detailed specification of discrete choice modelling, researchers can avoid oversimplifying the decision of residential location choices in its monocentric perspective. However, this model with hedonic prices is validated under the rather stringent assumption that prices are adequately estimated under equilibrium approaches. Hurtubia & Bierlaire (2011) developed a model capable of accounting for both the bid rent and location processes simultaneously.

Based on the residential location choices framework, to comprehensively investigate the factors that contribute to households choosing where to live, researchers typically characterise these factors in two aspects. One is to distinguish the individual preferences specification through the utility function and identify the optimal residential location via maximisation of their utility; another aspect is considering the constraints by limiting leisure time and consumption of the composite good (Díaz & Martinez, 1999; Thorsen & Ubøe, 2002).

3.1.2 What factors contribute to residential location choices?

One of the mainstream solutions to identify where households choose to live is to use the utility function. In economics, the utility function measures the welfare or satisfaction of a consumer as a function of consumption of real goods. It is widely used in rational choice theory to analyse human behaviour (Lovett, 2006). Additionally, it evaluates consumer preferences to determine a product's utility versus another and assigns a numerical value to that utility (Samuelson, 1938). In urban studies, utility functions refer to alternative sets that consist of various attributes (Guevara & Akiva, 2006). The relative weight of parameter estimates for these attributes provides insight into the tradeoff decision-makers make, such as the decision to prioritise location and socio-demographics, including income, age, and household composition (Schirmer et al., 2012). Cascetta et al. (2010) present an approach for identifying dominance attributes that can be characterised differently depending on the specific decision context and how they can be introduced as attributes in random utility models. Their methodology significantly improves the goodness-of-fit of the residential location choice models. Numerous studies have examined the various attributes that influence households in choosing where to reside (de Palma et al., 2007; Guo & Bhat, 2007; Habib & Miller, 2009; Lee et al., 2010; Schwanen & Mokhtarian, 2005). Although different attributes in different models cannot be directly compared, various attributes can be broadly characterised into three categories: location attributes, residence attributes, and household attributes (Schirmer et al., 2012).

Figure 6 illustrates the literature review of attributes that affect residential location choices. Location attributes refer to the location-related choice set, including urban zoning, neighbourhood, and residential unit attributes. A wide variety of factors describing location are considered in residential location choice studies, with each study categorising and operationalising spatial variables differently. Moreover, those factors are classified by Schirmer et al. (2014) into four main categories: build space attributes (i.e. built density, network and noise, urban character area), points of interest (i.e. education, service and retail, recreation, and sport, transportation), socio-economic attributes (i.e. school quality and diversity), and accessibility (i.e. accessibility of employments).

Waddell (2006) incorporates dwelling density in his residential location choice model and finds that the dwelling density has a negative impact on the residential utility for the households. Pinjari et al. (2009) consider a comprehensive set of activity-travel environment variables associated with the shape. Taking the length of networks and number of blocks per square mile into account, they find those bike lanes have a positive impact for all households, while the number of blocks has a negative impact on high-income households. Network-related attributes are also considered as built space factors. Bürgle (2006) finds that proximity to main motorways or railways has a negative effect on residential utility in the Zurich area. This factor is also used as a proxy of noise indicator in Vyvere et al.'s (1998) research. Besides, open space and land use are also considered when households decide on living places (Carrese et al., 2019; Chen et al., 2008; Guo & Bhat, 2007; Tang et al., 2021; Weisbrod et al., 1980; Yan, 2020; Zondag & Pieters, 2005). In Toronto, the presence of green areas positively affects households' choice of where to live, whereas industrial land use negatively impacts households when deciding living places (Habib & Miller, 2009).

In terms of points of interest (POI), it refers to the location of public facilities, which can be examined via the education institute, retail and service and recreation facilities in an area (Liu & Xiong, 2013; Yu & Chen, 2015). Many studies imply that the density of recreation facilities significantly enhances the location's utility (Yu et al., 2012; Choudhury & Bint Ayaz, 2015; Olaru et al., 2011; Pinjari et al., 2011). Beckers & Boschman (2019) also indicates that the knowledge workers prefer to reside in an area with abundant recreation facilities. As Guo & Bhat (2007) find, retail density has a positive effect on household location choices, whereas Zondag & Pieters (2005) suggest that services density has a positive impact on household location choices. In addition, a significant determinant of households to live in the area is influenced by educational institutions (Cockx & Canters, 2020; Rehman & Jamil, 2021). Axhausen et al. (2004) and Vyvere et al. (1998) reveal that living a long distance from the school has a negative impact on residential utility.

Socio-economics attributes are the most commonly investigated attributes in residential location choice literature, and they are mainly related to population density, school quality, employment, and diversity (Bayoh et al., 2006; de Palma et al., 2005; Pinjari et al., 2009, 2011; Weisbrod et al., 1980). Zondag & Pieters (2005) show that households generally dislike population density, except single households tend to be attracted to dense population areas. Similar results are reported by Kim et al. (2005) and Lee & Waddell (2010). Several studies investigate the impact of the unemployment rate on the residential location choice model (Olaru et al., 2011); Andrew & Meen (2006) and Habib & Miller (2009) both find a negative correlation between the unemployment rate and housing utility. Moreover, Frenkel et al. (2013) indicate that the knowledge workers in Tel-Aviv are more likely to live in the low unemployment rate area. Furthermore, as part of the residential locational choice model, school quality and diversity are used as explanatory variables (Kim et al., 2005; Zhou & Kockelman, 2008).

For many households, accessibility plays a significant role in the choice of residence (Zondag & Pieters, 2005). Accessibility is defined as the ease of reaching destinations for residences, and it refers to local and regional differences within the urban landscape (Wachs & Kumagai, 1973). The evidence from Belart (2011) indicates that the accessibility to the main road negatively influences residential utility if the workers own cars. Among households without private vehicles, Bürgle (2006) suggests that they prefer to reside in areas with high accessibility. Besides, Guo & Bhat (2007) show that employment accessibility has a negative effect on residential utility. Studies of residential location choices have also extensively discussed the accessibility of shops and city centres (Srour et al., 2002; Zolfaghari et al., 2012; Zondag & Pieters, 2005).

Residential property attributes refer to the property-related choice sets, including size, prices, costs, house type, and dwelling features. Lee & Waddell (2010) indicate that dwelling features tend to predominate over accessibility attributes in the residential location choices model. Using different measurements to capture the spaces needed by households, Axhausen et al. (2004), Belart (2011), and Bürgle (2006) have shown that households prefer more space per person and that this attribute is always taken into account when choosing the residential location of households. The size of the dwelling and number of bedrooms are also incorporated in some residential location choices model considerations (Eliasson, 2010; Habib & Miller, 2009). House price is another crucial factor of residential unit attributes in the location choice model. The value is expected to identify various location characteristics and be formulated by the regression model (Iacono & Levinson, 2011; Löchl & Axhausen, 2010; Taltavull., 2000). Guo & Peeta (2020) and Wu et al. (2013) imply that residential property price is a determinant in the residential location decision-making process, whereas Srour et al. (2002) suggest that the average property price in an area negatively affects the residential utility of a location. Besides, various studies suggest that house types are one factor in determining where to live (Axhausen et al., 2004; Vyvere et al., 1998). Habib & Miller (2009) evidence the negative utility of attached houses in Toronto, and Lee & Waddell (2010) indicate that single households prefer multifamily dwellings. Besides, dwelling features also are taken into account when households decide on living places (Srour et al., 2002; Vyvere et al., 1998), Jin & Lee (2018) find that the average building age negatively affects household residential location choices.

Households attributes denote the household characteristics, including age, household composition, lifestyles, and car ownership and commuting behaviour. The household attributes are applied using interaction terms and are used to identify the behavioural differentiation (Schirmer et al., 2012). Households with similar compositions prefer to live in close proximity to each other (de Palma et al., 2005). Sermons & Koppelman (2001) indicate that the presence of children is an essential determinant of commuting time and residential location utility of two-workers households. Chen et al. (2008) suggest that households with children are like to have more open spaces. Choosing a place to live involves the preference of lifestyle and lifecycle, which are another two factors of households attributes. Müller (1992) categorises the households into several different groups by considering their daily life behaviour, cultural and leisure preferences. Nine lifestyles have been identified by Krizek & Waddell (2002), and each of them will have different location choice preferences, such as urban density preference, travel distance preference. The residential location choices are shown to be influenced by lifecycle events such as marriage, employment change, household size, and retirement (Kim et al., 2005; Taltavull et al., 2005, 2009; Cheung et al., 2020).

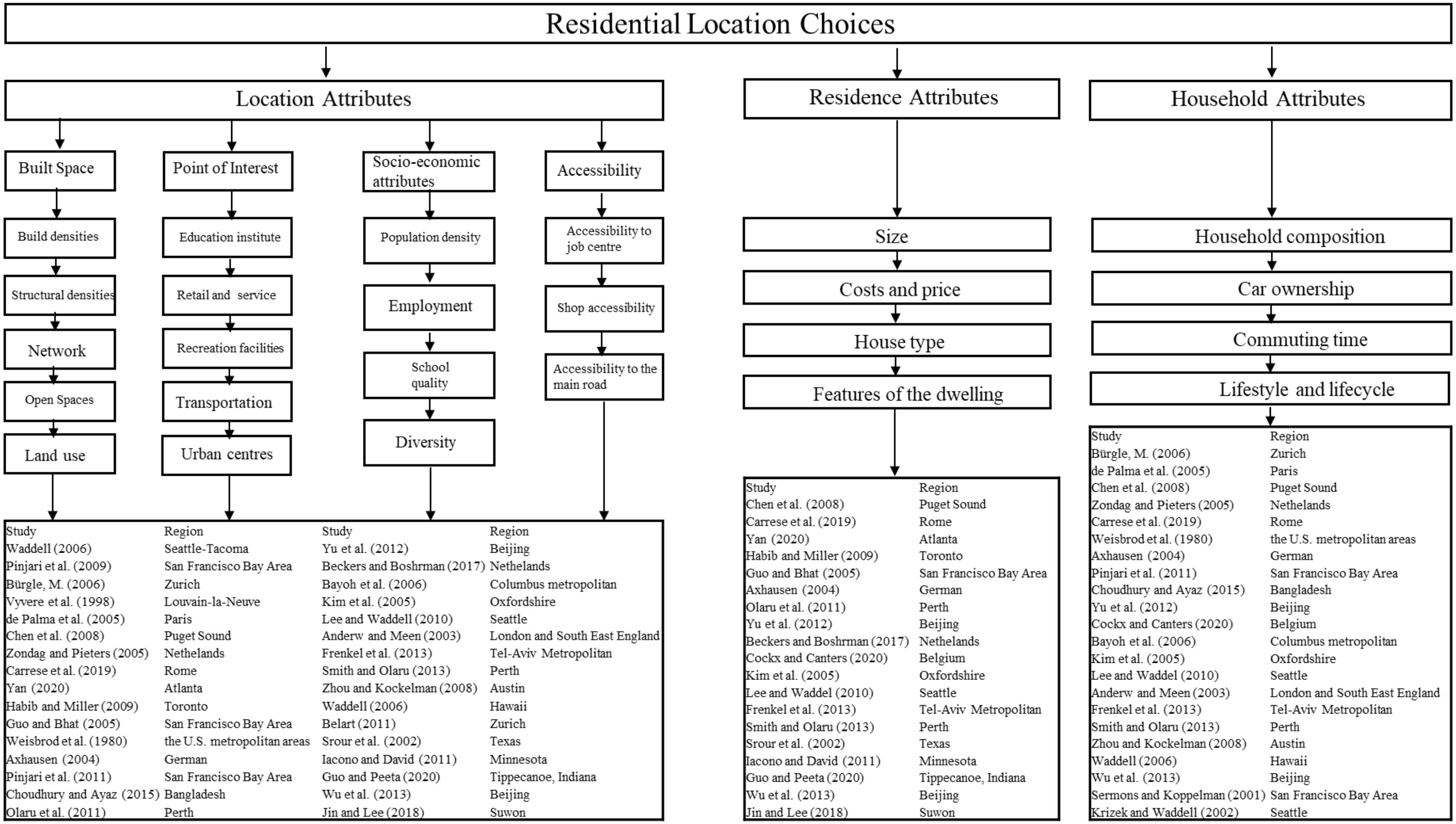


Figure 6 Literature review of residential location choices

3.1.3 What constrain the households in choosing where to live

Despite the fact that numerous factors will be part of households' considerations and influence household residential location choices in maximising their utility, households face a couple of constraints in choosing where to live (de Palma et al., 2007; Kim et al., 2005). Constraints related to income and time have been widely studied (Lee & Waddell, 2010; Olaru et al., 2011; Pérez et al., 2003). There have also been discussions of other constraints in the previous literature, such as uncertainties faced by households when making a decision, environmental justice, social status, and housing supply in the market (Taltavull., 2014; Gilbert & Ward, 1982; Kim et al., 2014; Tang et al., 2019; Turnbull, 1991; Yiu, 2011).

Income is an obvious constraint on residential location choices for almost every household (Moeckel, 2017). Household residence locational choices are generally optimised with respect to the household's budget under consideration of their income (Moeckel, 2017). In particular, for households who intend to access homeownership, even though loans and mortgages allow households to afford places that exceed their immediately available budget, households have to get along with their income in the long run. For low-income households, the options for where to live are very limited. Alonso (1964) initially proposed the bid-rent curve as the basis for the land use and urban location theory; his model considers the utility depends on the consumption, distance to the CBD and other attributes, subject to an income constraint.

Along with Alonso's (1964) research, many studies develop the residential location choice model by assuming that income is the only restriction in the model (Digambar & Mazumder, 2010; Pagliara et al., 2010). Borsdorf (2003) implies that the residential location of the high-income household is very different from low-income households, which reside nearby the industrial areas. White (1988a) indicates that the household residential location choice depends on their income level; his results show that high-income households are likely to choose to live near the job location usually located at the city centre.

It is more common to incorporate both income and time constraints in the residential location choices model (Eliasson, 2010; Hsu & Guo, 2006; Pagliara et al., 2010; Richardson, 1977). In particular, the time spent commuting, in leisure, and in work is considered in many previous studies (Cho et al., 2008; So et al., 2001; Wu et al., 2013). Having a long commute means less leisure time, affecting time with family, entertainment, and recreation (Freedman & Kern, 1997b; Frenkel et al., 2013). Commuting time is applied as a constraint in the residential location choice model; it usually has a negative influence on the residential utility (Axhausen et al., 2004; Guo & Bhat, 2007; Zhou & Kockelman, 2008). While the average commuting time does not change much more over time (Zahavi et al., 1981), Moeckel (2017) indicates that workers are inclined to reside closer to their work location if congestion worsens or the road situation becomes unstable. Similar results were found by Glaeser et al. (2008), implying that high-income households have a greater value of time and are likely to live closer to the city centres than low-income households to have short commuting time. If commuting time is not available, studies apply the travel distance, either network-based distance or Euclidean distance, in the constraint function as the proxy of constraints (Belart, 2011; Bürgle, 2006; Srour et al., 2002). Besides, few studies differentiate residential location choices between commuting time by different commuting modes (de Palma et al., 2007). Tran et al. (2016) incorporate the commuting modes choices in choosing residences. Their results show that knowledge-intensive workers face fewer constraints when deciding on living places and can choose a pair of work and residential locations that are compatible with their neighbourhood and travel preferences.

Decision on where to live is not just a temporary choice, but also a choice for long-term planning, even if it will affect households' entire life in the future (Yu et al., 2017). Residential location decisions are fraught with various uncertainties, which also constrain households' choices (Kochenderfer, 2015). Kan (1999, 2000) and Van Ommeren et al. (1998) find that the uncertainty of changing jobs affects households' intention to move, but fail to evidence the preference of the residential locations under job change uncertainty. Similar results are found by Crane (1996), who develops a theoretical model to prove that the uncertainty of future job location affects the commuting behaviours and constraints residential location choices. Turnbull (1991) introduces the housing quality uncertainty in the residential location choice model, and he indicates that the uncertainty of housing quality makes households prefer to choose the house near the CBD.

Studies have also been done on other constraints, such as the total household budget, social status, and land policy (Conder & Lawton, 2002; Li et al., 2016; Moeckel, 2017; Straszhem, 1987). Hsu & Guo (2006) and Ng (2008) discuss the residential location choices by maximising the residential utility subject to the household's budget. Gilbert & Ward (1982) suggest that government policy constraints towards land and servicing have also been considered in residential location choices. Besides, Banzhaf & Walsh (2006, 2008) found that residential similarity preferences mean that environmental disparities could worsen for the minority group, even as overall environmental conditions improved. Kim et al. (2014) suggest that the magnitudes of similarity preferences and racial proportions could also constrain the residential location choices.

3.2 Sub-optimal residential location choice and its consequences

3.2.1 Spatial mismatch hypothesis and job-housing imbalance

Households attempt to maximise their households utility to make the optimal choice when deciding the living places; however, the constraints above reduce the options available for residential location choices, resulting in households making sub-optimal decisions (Xiong et al., 2021; Zhao et al., 2011). Such sub-optimal residence choices based on those constraints are then translated into spatial segregation by the housing market (Dodson, 2004). Along with the sub-optimal residential location choice, similar households with a similar budget will agglomerate, particularly the lower status households. In other words, lower labour market status households are being separated into lower status housing areas and concentrated in an area. Problems of inequality employment opportunities potentially emerge, given that households with weaker labour market status are more vulnerable to the effects of employment decline and make those households disadvantaged. Therefore, such locational disadvantage can compound the effects of weak labour market status, the geographic differential between locations where housing is more accessible or affordable for those on low incomes, and locations where employment opportunity is greatest. This geographic differential is a so-called spatial differential mismatch in urban study literature.

The Spatial mismatch hypothesis has been initially come up by Kain (1968), who developed and tested it by analysing how spatial mismatch affects employment and job opportunities of inner-city's Africa-American. Kain (1968) investigated the employment of inner-city's Africa-American in both Chicago and Detroit. He suggested that the job decentralisation and the disconnection from suburban job opportunities of inner-city Africa-American could be attributed to racial discrimination in the housing market. Spatial mismatch hypothesis suggests that those Africa-American who reside in inner-city unable to fill the positions located in the suburban area would deteriorate their employment opportunities as well as exacerbate labour-market outcomes (Ihlanfeldt, 2006). Ihlanfeldt (2006) also indicates that job decentralisation was more severe after World War II. Gobillon et al. (2007) conclude that the primary factor that leads to the high unemployment rate and low wages of inner-city Africa-American could be the low-skill job in suburbs inaccessibility.

The spatial mismatch that occurs in U.S. cities can attribute to various factors. Ross (1998) suggested that racial discrimination in the housing market could restrict inner-city Africa-American mobility and their job choice. To be precise, the property agent prevents those minority groups from becoming homeownership in the white-predominant areas (Ihlanfeldt & Sjoquist, 1990) as well as the inaccessibility of low-cost housing in the suburbs (Kasarda, 1989). Also, Ihlanfeldt & Sjoquist (1990) indicated that this situation caused residential choice barriers for inner-city blacks who intend to move to the suburbs. The distance from residence to suburbs job location makes it the low-skilled and low-education blacks hard to commute to the jobs and increases the cost of job search (Gobillon & Selod, 2021). Crampton (1997), Martin & Morrison (2003), O'Regan & Quigley (1998), and Wilson (2012) also suggested that job seekers who need to rely on public transport to further job place might restrict their job search and commuting costs would harm the job choice for inner-city minorities. Furthermore, local zoning regulations such as the minimum requirements of lot sizes would trigger house price rising (Fischel, 1987; Glaeser et al., 2005; Glaeser & Gyourko, 2002; Rothwell & Massey, 2009), in particular, the white areas; and such zoning regulation would prevent the outflow of not only low-income people but also the modest-income people in segregated areas (Rothwell & Massey, 2009).

3.2.2 The consequence of the spatial mismatch

The spatial mismatch exacerbates the imbalanced labour-market outcomes of Africa-American residing in central cities. Browne (2000) suggested that young black women had fewer opportunities to be employed due to they were concentrated in central cities. To avoid neighbourhood selection, Weinberg (2000) tried to measure the effect of Africa-American residential centralisation for their employment across metropolitan areas, and he also found that Africa-American centralisation caused a considerable difference in employment between black and white. The young, elderly and individuals with less than a college education will be influenced most. Martin & Morrison (2003) and Martin (2001) found the trend of the suburbanisation of job opportunities affected the population structure in American metropolitan areas, and this tendency spread out metropolitan areas. He also found African-American residents were attracted to those areas, where initially the edge of the metropolitan areas. Furthermore, one pronounced outcome of spatial mismatch is the significant rise in commuting costs. Cervero (1989) found that the distance from residence to job centres could explain the job-housing imbalance. Ihlanfeldt (2006) also summarised the spatial mismatch lead to higher unemployment of Africa-American as well as increase both travelling time and financial costs of commuting.

3.2.3 Spatial mismatch and key worker issue

Over the past decade, research interest in spatial mismatch has shifted its focus, and the spatial mismatch hypothesis has been extended to a broader research area. One of the spatial mismatch related research is the increasing difficulty of accessing affordable housing for key workers in the UK, particularly in London and some South-East areas nearby London

(Morrison, 2003; Raco, 2008). Great London Authority (2001) finds the shortage of affordable housing partially caused the critical problems in recruitment and retention of public sectors workers in London. The Office of the Deputy Prime Minister (2003) addressed the growing unaffordable housing issues in the UK and indicated that their target group was the workers who earned too much money to qualif the social housing but not earned enough to afford the housing nearby where they worked rather than the “working poor.” Morrison (2003) argued that housing costs contributed to staff recruitment and retention problems for key workers and other workers by conducting a survey in Cambridge. Morrison & Monk (2006) further studied key worker issues in Surrey near London, and they found that recruitment and retention problems occurred in the public sector and low-income private sectors. Studies about key workers issues focus on the relationship between the labour market and the housing market. Many local authorities are concerned about the problem of delivering community services led by the labour shortage in public sectors because of the high housing costs. Moreover, they trigger housing affordability to staff recruitment and retention problem. The studies in the UK discussed a few about the relationship between housing cost and mobility of key workers.

Another stream of spatial mismatch application mainly focuses on structural inefficiencies in urban labour markets (O’Connor & Healy, 2002; Yates et al., 2006). Berry & Dalton (2004) indicate that rapid house price inflation extended numbers of years of median income households to purchase median price houses in major cities such as Sydney and Melbourne and limited the residential choice in inner and middle suburbs for low-income households. Burke & Hayward (2001) investigated the house price dynamics in Melbourne and found that house prices sharply rise in the inner ring of Melbourne, limited the residential choice for low-income first homebuyers and pushed them to outer-ring suburbs. They also found a group of low-income households who were not poor enough to get into public housing but had a barrier to become homeownership due to different housing price dynamics in inner ring and suburbs. Dodson (2004) identifies the spatial segmentation of housing market and the labour market in Melbourne and finds that the areas with a high growth rate of employment are the adjacent with the areas having the high unemployment rate, and he also indicates that the low-income workers were price out from urban area where was the job-rich area. The studies above tried to address the spatial mismatch in Australia, concern the relationship between the housing market and labour market and took more effort on studying the housing market dynamics and housing affordability. EpicDotGov (2004) conducted a study on low to modest income occupations that provide essential services to the community in Sydney and function similarly as key workers in London. Their results suggest that the housing cost was not a factor that affected the key workers' employment because many key workers are homeownership. Blunden et al. (2004) find that housing costs crowded out the key workers in Eastern Suburbs of Sydney. However, their study only covers the bus driver. Yates et al. (2006) evidence that housing costs do not influence inner-city key workers employment because the inner-city key workers have a high tolerance of high housing costs and prevent from moving out.

3.3 Research Gaps

Based on the detailed literature review on residential location choices and the consequence of spatial mismatch associated with sub-optimal residential location choices, four research gaps are identified, which are worth a thorough investigation.

First, it is the residential location choices of multiple-worker households. It is important to know how the residential location choices are affected by considering the multiple-worker households. In reality, households are more likely to involve multiple workers. However, most previous studies in the literature were focusing on single-worker households. The households take into account the utility of their members in making location decisions and maximising the utility of the households. There have been previous studies that either present a mathematical calculation of the choice of residential locations (Curran et al., 1982; Ommeren et al., 1998; White, 1977) or focus on dual-earner households consisting of husbands and wives (Chiappori et al., 2012; Freedman & Kern, 1997; Mok, 2007). A few studies develop the theoretical framework and provide empirical evidence on how multiple-worker households choose residence (Marcucci et al., 2011). It is necessary to study the multiple-worker households residential location choices.

Second, it is about how uncertainties affect the residential location choices. Various attributes have been considered and studied in the previous literature to analyse the residential location choices; however, many of these studies assume a perfect world with full certainties. Given that households are uncertain about many factors when making their housing consumption and location decisions (Yiu, 2011), this is important to incorporate uncertainties in the residential location choice models. The introduction of uncertainty into the urban location theory is not something new (Andrulis, 1982; DeSalvo & Eeckhoudt, 1982; Papageorgiou & Pines, 1988; Turnbull, 1991, 1995), but lack of research works apply uncertainties in the residential location choice studies, especially on the occupation perspective. Workers with different occupations have varying turnover rates and employee loyalty, and some may have permanent contracts, which result in different possibilities of changing jobs. The urban location studies have failed to investigate the spatial patterns by considering such occupational differences. On the one hand, while workers have the potential to change jobs, most residential location models assume they will maintain the same job with a certain job location for the rest of their lives. Residential location choice models have failed to account for uncertainty associated with the job location. On the other hand, the differences in spatial distributions caused by various residential location choices associated with various occupations have not yet been studied. It is crucial to understand households choosing living places under job location uncertainty and identifying the jobs-housing spatial distribution caused by occupational differences.

Third, it is necessary to measure how housing affordability constrains the households' residential location choices and further affects the spatial mismatch. Affordable housing is a key challenge facing New Zealand, particularly in the Auckland Region. The deteriorating housing affordability limits the workers' residential location choices, and workers have to reside in the suburbs and lead to middle, and even outer ring areas become unaffordable and failed the opportunities of workers to be homeowners (Bangura & Lee, 2019; Weller & Hulten, 2012). Previous studies suggest that the inability of key workers to live in high-cost metropolitan regions can have significant implications for the quality of essential services and the functionality, including the health and safety, of cities. Particularly in England, many cities face recruitment and retention difficulties in essential public services industries (Airey & Wales, 2019; Morrison, 2003; Morrison & Monk, 2006). However, the previous studies did not assess the influence of housing affordability on spatial mismatch and the magnitude of spatial mismatch by occupations.

Auckland is the most populous metropolitan in New Zealand; homeownership rates have fallen in every region since 1991 (Ministry of Housing and Urban Development, 2021). However, to the best of my knowledge, none of the literature studies household's residential location choices in the Auckland context. Besides, there is an increasing trend in elderly populations in New Zealand, more than seventeen per cent of the workforce work as key workers, such as nurses, teachers, et cetera, across the Auckland region. Nonetheless, to the best of my knowledge, none of the research attempts to address the housing need of key workers in Auckland.

The following two chapters will focus more specifically on the multiple-worker households residential location choices under the uncertainty and the outcome of sub-optimal residential location choices, which is the spatial mismatch of key workers. Chapter 4 attempts to fill the gap in the literature on spatial mismatch hypothesis by theorising and extending the testable implications of the hypothesis on workers' occupations. Chapter 5 aims to incorporate the concept of the uncertainty in residential location choices of multiple-worker households.

Chapter 4

Spatial Mismatch and Housing Affordability of Key Workers

In New Zealand, the shortage of affordable housing in its main urban centres is forcing a group of workers who provide essential public services for the communities (also known as "key workers") to move further out of the city to access cheaper housing, thus increasing their workplace commuting costs. This raises problems for the sustainability of the local economy. In this chapter, I aim to empirically examine how the housing affordability crisis distorts the residential choice of key workers in New Zealand's most populous city, Auckland. The study in this chapter quantifies such negative externalities in terms of the additional commuting costs involved due to the job-housing locational mismatch. The results indicate that for key workers, a one per cent increase in a housing unaffordability measure (i.e., mortgage repayment relative to the annual income) will result in an extra "two-kilometre" commuting distance – that is the equivalent of $90 million deadweight loss a year. This chapter highlights that such sub-optimal residential locational costs are most severe for key workers compared with other occupational groups. The findings also imply that policymakers seeking to mitigate the problem of sub-optimal residential locations by addressing housing affordability issues through developing affordable housing should take into account transportation infrastructure and site selections.

4.1 Introduction

In various international studies over the decade, house prices in New Zealand are regarded as severely unaffordable (Hartwich, 2017). A group of low- to moderate- class professionals identified as key workers[3], including but not limited to nurses, teachers, and

[3] Key workers are also known as "essential workers" or "critical workers" in different countries. The term has been used in the United Kingdom for workers who may find difficult to buy property in the area where they work. The term was also used by different governments during announcements regarding school shutdowns invoked in response to the Coronavirus pandemic to indicate those occupations entitled to continue sending their children to schools which were otherwise the movement would be constrained by the government lockdown policy.

police officers, who provide essential services, are significantly affected and have to make residential location choices away from their places of work. Indeed, the national lockdown due to the COVID-19 pandemics across global cities further highlights that the stress of commuting for key workers is significant and even inevitable (Gilbert et al., 2021). The increasing imbalance in the job-housing locations has contributed to a so-called "spatial mismatch" among key workers. The phenomenon of spatial mismatch in urban economics refers to the geographical disconnect between the housing in which low-income workers reside, and their workplaces (Holzer, 1991; Kain, 1968, 1992). Although the concept of spatial mismatch was initially applied to African-American workers in the United States, the theory can be extended to various disadvantaged worker groups, including key workers.

While socioeconomic factors, such as neighbourhood effect, family structure, and government services influence workers' locational preferences in general (Astone & McLanahan, 1994), the spatial mismatch literature apparently puts less emphasis on the impact of housing affordability on the residential location choice of specific worker groups. When households consider relocation, the optimal distance between their workplaces and living places becomes integral to their decision-making. Key workers are no exception, and this decision is particularly relevant to them because many of the essential occupations require tenured appointments and are characterised by low turnover rates within their industry sectors (Lawson Williams, 2018).

This chapter examines how deteriorating housing affordability affects the spatial mismatch of key workers in Auckland, which is the most populous city in New Zealand. Key workers in this study are defined as those who work in the public sector and provide essential services (Morrison & Monk, 2006; Weaver, 2004), and these workers account for more than 17% of the national workforce. Usually, they work in permanently fixed locations such as schools and hospitals. Some of these key workers struggle to secure homeownership as they earn too much to qualify for subsidised housing but too little to purchase housing at market prices.

We have utilised two waves of census data in New Zealand to analyse the relationship between housing affordability and spatial mismatch of key workers. The findings suggest that worsening housing affordability is a significant determinant of a spatial mismatch for key workers in Auckland, after other socio-economic factors are controlled. Also, the results reveal that key workers suffer from more severe spatial mismatch than workers in other industries, namely financial and insurance workers and retail trade workers. Relative to these two industries, key workers have fewer employment location choices and hence experience longer travel distances, resulting in $90 million social costs.

The study presented in this chapter is novel in several ways. First, to the best of my knowledge, it is the first study to theorise the concept of spatial mismatch in relation to the key worker group. The empirical results confirm that the deteriorating housing affordability significantly increases the spatial job-housing mismatch of key workers. In 2013 a one per cent increase in the ratio of annual mortgage repayments to household income could be expected to increase the spatial mismatch (measured by excess travel distance) by 0.093 per cent, referring to 2.4 km excess travel distance and $839 extra commuting costs of a key worker. Second, this chapter offers insights into how constrained housing affordability limits key workers from securing homeownership in locations near their workplaces, which is a common issue prevailing in many global cities. The findings also suggest that when governments are addressing housing affordability issues, their policies for affordable housing development should seek to mitigate the problem of sub-optimal residential locational choices by taking into account transportation infrastructure and site selections. Third, this chapter develops a new measure to examine the degree of a spatial mismatch at an aggregate level by constructing a travel distance matrix that measures the excess of commuting distance for different occupational groups based on most of their possible working and living locations. The spatial mismatch measure allows us to better capture the locational mismatches of all the possible workplaces[4]. To estimate the magnitude of spatial mismatch without committing potential omission bias, we make use of other occupational groups as controls (i.e., counterfactuals) to serve as a benchmark in the modelling. The across group comparison verifies that key workers face the most severe spatial mismatch of residential choice (at least in a relative sense), while retail trade workers and financial and insurance industry workers suffer less severe spatial mismatches.

This chapter will be structured as follows. Section 4.2 provide a literature review on the housing market and contextualise the spatial mismatch problem among key workers. Section 4.3 develops the testable hypotheses. Section 4.4 presents the data and outlines the empirical models for the analysis. The results are discussed in section 4.5. Section 4.6 presents the limitations and conclusion.

4.2 Literature review on spatial mismatch

Spatial mismatch is a topic in urban studies that relates the sub-optimal labour-market outcomes of unskilled ethnic minorities to the geographic disconnection between the

[4] Previous studies calculated either the travel time or distance to measure the magnitude of spatial mismatch (Ihlanfeldt & Sjoquist, 1989; Kain, 1968). Ihlanfeldt & Sjoquist (1990) easily used mean travel time as a measurement while Giuliano & Small (1993) considered transportation model and maximum commuting in peak time. Horner (2002) measured the mismatch by considering the theoretical minimum and maximum commuting together with different traffic zones.

neighbourhoods where these groups reside and their job locations (Gobillon & Selod, 2014). The spatial mismatch hypothesis was initially formulated by Kain (1968), who developed and tested it by analysing how spatial mismatch affected employment and job opportunities of inner-city African-American ethnic groups in both Chicago and Detroit. Kain (1968) suggested that the job decentralisation and the disconnection from suburban job opportunities of inner-city Africa-Americans could be attributable to racial discrimination in the housing market.

There are numerous studies measuring the extent of jobs-housing imbalance pointing to the segregation in both the housing and job markets (Bi et al., 2019; Brueckner & Zenou, 2003; Gobillon et al., 2007; Li et al., 2013; O'Kelly & Lee, 2005; Stoll & Covington, 2012; Wang et al., 2011; Weinberg, 2000). Massey & Denton (1993) found that racial segregation was responsible for the persistent poverty and geographically concentrated residences of African-Americans. Ross (1998) suggested that racial discrimination in the housing market could restrict the mobility and job choices of inner-city Africa-Americans.

Recent studies have attempted to apply spatial mismatch to low-income workers. They have started to focus on discussing how particular occupations, household types, demographic groups, and gender contribute to spatial mismatch (Fan et al., 2014; Hui et al., 2015; Zhao, 2015). Zhou et al. (2016) found that institutional transformation brought out the spatial mismatch for low and middle-income workers. Qi et al. (2018) found that the low-educated migrant population in Beijing suffered from a severe spatial mismatch. Pastor & Marcelli (2000) discussed male workers' wage differences in Los Angeles and concluded that spatially based skill mismatch influenced their labour outcomes. Carlson & Theodore (1997) explored the relationship between neighbourhood characteristics and job availability at the individual level. They found that neighbourhood racial composition determined the job opportunities of low-income workers. Lau (2011) focused on analysing the cost of commuting to low-income workers in Singapore and indicated that the redevelopment of new towns contributed to the spatial mismatch of low-income workers.

Gobillon & Selod (2014) concluded that the distance from residence place to suburban job locations makes it hard for low-skill and low-education African-Americans to commute to the jobs and increases their costs of job searching. Crampton (1997), Martin & Morrison (2003), and Wilson (2012) also suggested that job seekers who need to rely on public transport to travel to distant job locations might restrict their job searching and that commuting costs would limit the job choice for inner-city minorities. Furthermore, local zoning regulations such as the minimum requirements of lot sizes would cause house prices to increase (Glaeser & Gyourko, 2002), and would prevent low- and middle-income households in segregated areas from moving (Rothwell & Massey, 2009).

However, the spatial mismatch literature appears to put less emphasis on key workers. Morrison (2003) is one of few researchers concerned about the increasing difficulty of accessing affordable housing for key workers in the U.K. and argued that housing costs could contribute to staff recruitment and retention problems. Morrison & Monk (2006) further studied key worker issues in Surrey and found that recruitment and retention problems occurred in the public and low-income private sectors. Another stream of research on key workers focuses on structural inefficiencies in urban labour markets (O'Connor & Healy, 2002; Yates et al., 2006). Epic DotGov (2004) studied low- to middle-income occupations which provided essential community services in Sydney. However, their results suggested that the housing cost was not a factor. Yates et al. (2006) suggested that housing costs did not influence the employment of inner-city key workers as they had a high tolerance for expensive housing costs.

4.3 Hypothesis development on spatial mismatch of key workers

Consider a constrained locational choice problem for an individual worker. For the sake of simplicity, a worker requires to choose only the residential location ($X_{R.}$) and job location (X_L). Each location choice bundle (X^*_R, X^*_L) would give an individual worker a satisfaction (or utility) level U. This satisfaction level would consist of the utility U_R and U_L, which is the satisfaction associated with the residential location and job location respectively. For each location, it involves a cost to commute. $C_{R.}$ is the per-unit cost of commute at a given residential location, whereas C_L is the cost of the job location. Similar to any constrained optimisation problem, the choice of a locational bundle is subject to income and time constraints. B is the income available for a worker, $T_{R.}$ and T_L is the corresponding time used to travel from residential locations to job location. $T_R + T_L$ is the total time (T) available for a worker (i.e., 24 hours minus sleeping time). Thus, the mathematical formulation of the constrained maximisation problem is as follows:

$$\max_{X_R, X_L} (U_R X_R + U_L X_L) \text{ ((Objective function)} \quad (1)$$

$$\text{Subject to } C_R X_R + C_L X_L \leq B \text{ (Income constraint)} \quad (2)$$

$$T_R X_R + T_L X_L \leq T \text{ (Time constraint)} \quad (3)$$

where C_R *and* $C_{L,}$ is the cost of living (e.g. dining expense) when one choose location X_R to reside and location X_L to work; B is the total income available; T_R *and* T_L $T_R + T_L$ is the corresponding time used to travel from residential locations and job location, respectively; T is the total time available; and U_R *and* U_L are the satisfaction of living at location X_R and working at location X_L, respectively.

In reality, the locational choice problem may be much more complex, and we can complicate the optimisation problem to capture that. In Figure 7, with the residential locations shown on the x-axis and job location on the y-axis, Line BF is the income constraint limiting an individual disposable income. Line CE is the time constraint limiting the total time available for a worker each day. Any point to the southwest of these constraints will be the feasible time and income that do not exceed the respective limits.

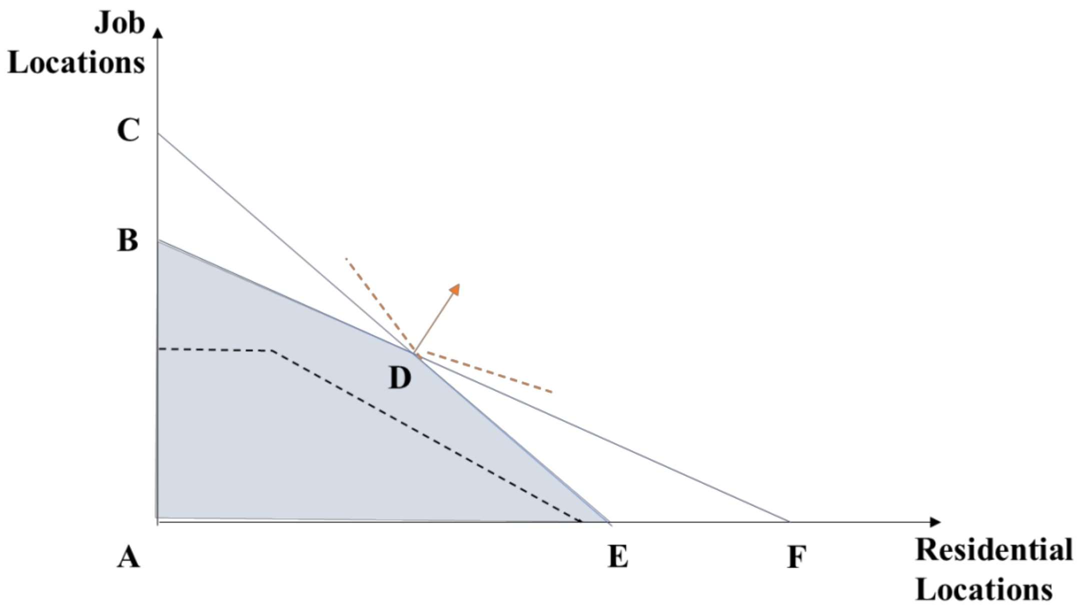


Figure 7 Graphical representation of a simple constrained locational choice problem

The shaded quadrilateral AB-BD-DE-EA form the boundary of the feasibility locational choices. All pairs of residential locations and job locations (X_R, X_L) give a feasible locational choice set. In problems that involve more constraints, this quadrilateral could be hyperplanes. To obtain the optimal solution (X^*_R, X^*_L), the red dashed line is established, and the slope depends on the relative satisfaction associated with the two locational decision variables. This red dashed line moves from the origin in the northeast direction and when it attains the outermost locational choice bundle, the optimal locational choice is achieved. At this optimal choice, a worker is capable of achieving a higher satisfaction level given the time and income constraints.

Considering the choice bundle of key workers who have limited job location choices. Two features of key workers make their constrained locational choices problem differ from that of other workers. First, key workers usually have a permanent (tenured) job in an organisation where its office is at a given location (i.e., the choice of X_L is fixed) or have a relatively lower turnover rate and work for one institution for a long period. Therefore, the value in the y-axis of key workers should be smaller than other workers. Second, key workers who are homeowners bear an additional mortgage expense in their income constraints. Thus, their income constraint inequality will be $C_R X_R + C_L X_L + M \leq I$, where M is the mortgage cost.

The research question of this chapter is: **How does deteriorating housing affordability influence the residential locational choices of key workers?** The feasible set of locational choices for key workers (indicated by the black quadrilateral in Figure 7) has to be smaller than that of other workers. It is a subset of the quadrilateral ABDE and is sub-optimal and inferior to that of other workers. Such sub-optimal locational choice will imply a more considerable spatial mismatch. Thus, we hypothesise that:

Hypothesis: Ceteris paribus, the deteriorating housing affordability will significantly increase the spatial jobs-housing mismatch of key workers.

4.4 Research design and methodology of spatial mismatch measurement

Theoretically, either restriction of, or barriers to, residential choices can cause a spatial mismatch. This study aims to examine how the extent of housing affordability influences the extent of a spatial mismatch for the key worker group. The empirical test to examine the relationship between housing affordability and the spatial mismatch consists of two parts. First, regression-based on census years data is applied to identify the extent of spatial mismatch of key workers between 2001 and 2013. Second, the degree of spatial mismatch among different workers' groups, including finance and insurance workers, retail trade workers, and key workers, is compared. Then, seemingly unrelated regression (SUR) is used to compare the impact of housing unaffordability on the spatial mismatch across different worker groups and to validate the significance of the differences. The comparison groups have been considered is to control the preference in choosing living places. Besides, finance and insurance workers and retail trade workers have been chosen for the following reasons. First, considering the lower turnover rate nature of key workers, this thesis includes a worker group with a higher turnover rate at a similar income level. Retail trade workers have been added as one of the comparison groups. Second, this thesis employs finance and insurance workers as another comparison group due to finance, and insurance workers are at a similar level to the turnover rate of key workers. There are many financial branches across the city, and finance and insurance workers may have loyalty to the institution and work for a permanent branch for a long period. However, finance and insurance workers have a higher income, and they would rarely be constrained in choosing living places compared with key workers who are at a low to moderate-income level. Third, the data availability has been considered since it is feasible to collect the workplaces information of finance and insurance workers and retail trade workers. The list of financial institution branches and distribution of retail shops can be found.

4.4.1 Spatial mismatch index construction

In order to capture the spatial mismatch, a travel distance matrix for different occupation groups is therefore constructed. Workers living in each area unit[5] are assumed to have the same probability of travel to each potential workplace irrespective of the type of occupation. An excess travel distance matrix is prepared for measuring the extent of spatial mismatch (***SPI***). The following notation will be used:

i is the index of trip origin which are the centroids of area units

j is the index of trip destinations which are the job locations

o is the index of occupational type

t is the census year

$D_{i j_{ot}}$ is the real commuting distance of *o* workers from area unit *i* to job location *j* at time *t*

Figure 8 illustrates how this distance matrix is constructed. The first column of the matrix is the (population-weighted centroids of) area units, while the first row is the coordinates of potential job locations for workers. Thus, the aggregate real commuting distance for workers *o* is:

$$\text{Aggregate real commuting distance} = \sum_i^n \sum_j^m D_{ijt}^o \qquad (4)$$

where D_{ijt}^o denotes the real commuting distance for worker types *o,* who reside in area unit *i and* work in location *j* at census year *t*. *o* could refer to key workers, finance and insurance

[5] Area units are non–administrative areas that are in between meshblocks and territorial authorities in size. Each area unit must be a single geographic entity with a unique name referring to a geographical feature.

workers and retail trade workers while t could denote census year 2001, and census year 2013. Provided that each area unit i has N^o_{it} numbers of o workers' workplaces in year t, the average real commuting distance is:

$$\mu^o_{ijt} = \frac{1}{N^o_{it}} \sum_i^n \sum_j^m D^o_{ijt} \qquad (5)$$

Workers in each area unit i are considered to have the same probability of accessing any potential workplaces. μ^o_{ijt} denotes the average real commuting distance of worker type o who lives in area unit i in year t. Like other measures of variability that assess how "dispersed" the commuting distance is, the mean commuting distance μ^o_{ijt} is subtracted by the shortest commuting distance $\underline{D}^o_{ijt}$ which equals to the distance between the centroid of area unit i and the closest workplace $j_{closest}$ in census year t, and then normalised by the median travel distance $\tilde{\mu}^o_{ijt}$ to create the spatial mismatch index (SPI) measure:

$$SPI^o_{ijt} = \frac{Excess^o_{ijt}}{\tilde{\mu}^o_{ijt}} = \frac{\frac{1}{N^o_{it}} \sum_i^n \sum_j^m D^o_{ijt} - \underline{D}^o_{ijt}}{\tilde{\mu}^o_{ijt}} \qquad (6)$$

Workplaces / Area Unit	Auckland City Hospital	North Shore Hospital	Rodney College	Henderson High School	…	j_{ot}	Manurewa High School
Wellsford	78382.164	67542.633	748.610	83023.477	…		99539.055
Leigh	80771.547	69932.016	34200.434	85412.859	…		101928.444
Warkworth	58964.781	48125.246	20480.545	63606.094	…		80121.672
Orewa	36685.715	25846.182	45599.969	41327.027	…		57842.602
…							
i	…						
New Lynn South	11195.699	20724.947	86832.891	6197.042	…	…	25790.867

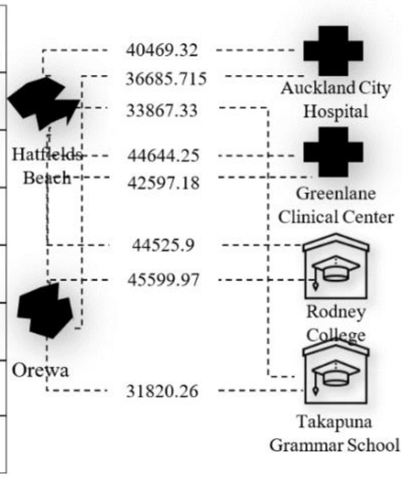


Figure 8 The excess commuting distance matrices

The spatial mismatch index (SPI) measures the magnitude of excess commuting of a specific occupation in one census year. The higher the spatial mismatch ratio, the worse the excess commuting for a specific group of workers in one area unit. When $t = 2013, o = keyworkers$, $SPI_{i,2013}^{keyworker}$ indicates the average excess commuting distance of key workers who live in area unit *i* in the year 2013. When $t = 2001$ $SPI_{i,2001}^{keyworker}$ indicates the average excess commuting distance of key workers who live in area unit *i* in the year 2001. When $t = 2013, o = finance\ and\ insurance\ workers\ (FIN)$, SPI_{FIN} indicates the average excess commuting distance of finance and insurance workers who live in area unit *i* in the year 2013. When $t = 2013, o = retail\ trade\ workers\ (RET)$, SPI_{RET} indicates the average excess commuting distance of retail trade workers who live in area unit *i* in the year 2013. And SPI_{BEN} indicates the average excess commuting distance of all workers who live in area unit i in the year 2013.

4.4.2 Descriptive statistics of spatial mismatch measurement

This chapter focuses on 334 area units in Auckland from 2001 to 2013, and the data are drawn from several sources. First, to construct the SPI, we collect the potential workplaces of three types of workers to calculate the excess commuting distance for different types of workers in each area unit. State schools and public hospitals are chosen to represent the key workers' workplaces, all commercial banks branches are used as the proxy for financial and insurance workers' job locations, and supermarkets to represent retail trade workers' workplaces. The addresses of workplaces are taken from the Ministry of Health, Ministry of Education, and commercial banks, and the two largest supermarket chains in New Zealand. The total numbers of the workplaces of key workers are 497 in the year 2001 and 513 in the year 2013.

Furthermore, there are 208 bank branches and 75 supermarkets in the year 2013. The real commuting distance is collected as of 2001 and 2013 based on the road layout in those years. Geocoding was used to locate workplace addresses, compute an area unit centroid, and to estimate the real commuting distance between the centroid of an area unit and a series of workplaces. SPI is calculated by normalising excess commuting distance for the three types of workers in each area unit. The excess commuting distances of the benchmark are the distances between the centroids of area units irrespective of occupations.

Table 4 Description of variables and summary statistics

Description	Variable	Year	Mean	S.D.	Min	Max
Panel A						
Excess commuting distance from the centroid of an area unit to the identified workplaces of:						
Key workers - (e.g. state schools; public hospitals)	Excess $_{KEY}$ (m)	2001	26943	11424	17712	93777
		2013	26620	10522	17638	87980
Financial & insurance workers (e.g. bank branches)	Excess $_{FIN}$ (m)	2013	20986	9351	12536	85236
Retail trade workers	Excess $_{RET}$ (m)	2013	21403	7013	13914	46164
Centroids of other remaining area units	Excess $_{BEN}$ (m)	2013	24501	9732	16380	90509
Panel B						
Median Multiple of an area unit	UnAff	2001	0.349	0.102	0.186	1.35
		2013	0.487	0.148	0.144	1.94
Mean number of usual household members in an area unit	HHSIZE	2001	2.955	0.545	1.8	5.4
		2013	3.045	0.552	1.9	5.2
Percentage of household homeownership in an area unit	HMOWN	2001	0.598	0.142	0.191	0.858
		2013	0.423	0.113	0.117	0.702
Median age of people who reside in the area unit	AGE	2001	33.59	4.853	22.4	52.5
		2013	35.74	5.928	22.4	57.4
Percentage of workers who take public bus or train to work in an area unit	PUBLICT	2001	0.028	0.025	0	0.217
		2013	0.033	0.032	0	0.281
Socio-economic position of a school's student community relative to other schools	SCHOOLDECILE	2001	4.458	3.424	1	10
		2013	4.907	3.512	1	10
Socio-economic deprivation index score of an area unit	NZDEP	2001	5.329	2.748	1	10
		2013	5.395	2.807	1	10

Notes: Total observation is 334. School deciles are a measure of the soci-economic position of a school's student community relative to other schools throughout the country. It does not measure school performance or the quality of education. In general, decile 1 schools are the 10% of schools with the highest proportion of students from low socio-economic communities, whereas decile 10 schools are the 10% of schools with the lowest proportion of these students.

Table 4 shows that the excess commuting distance of workers (Excess_{BEN}) is 24.5 km irrespective of the workers' occupation, meaning the workers travel 24.5 km more when they do not reside in the same area unit. In the worst-case scenario, workers need to travel 90.5 km more than average to work, while the optimal travel distance is 16.4 km. In 2013, the excess commuting distance of key workers (Excess_{KEY}), 26.6 km, suggests that the key workers may have a relatively long travel distance of 26.6 km compared with their optimal residential location. Moreover, in the worst-case scenario, they will need to travel around 88 km more to commute, while in the best-case scenario, they will travel around 17.6 km more. Compared with 2013, both the minimal excess travel distance and the maximal excess travel distance are shorter than the distance in 2001, which means that improvements in the road network have shortened the commuting distance. The financial and insurance workers (Excess_{FIN}) have the shortest excess commuting distance, 21 km, while the retail trade workers (Excess_{RET}) travel 21.4 km more. The excess commuting distances of both financial and insurance workers and key workers are shorter than the benchmark case (Excess_{BEN}).

Second, data relating to housing affordability are sourced from the Reserve Bank of New Zealand (RBNZ) and CoreLogic. The loan to value ratio is assumed to be 90% on average, and this data is from the RBNZ (RBNZ, 2018). In addition, the RBNZ also provides two-year fixed mortgage rates, which were 7.2% and 5.6% in the two census years. The housing unaffordability (UnAFF) is 0.349 and 0.487 in the two census years, denoting that 34.9% of annual income is used to repay the mortgage in 2001, while 48.7% of annual income is used to repay the mortgage in 2013.

The remaining data are sourced from Statistics New Zealand and the Ministry of Health. The number of household members, the proportions of households that are owner-occupants in an area unit, median age, and the proportions of workers taking a public bus or train to work in an area unit are derived from 2001 and 2013 New Zealand area unit level census data. There are three members on average in a household in both 2001 and 2013, and the median age is around 34 years in 2001, and around 36 years in 2013. In addition, the average percentage of homeownership being 59.8% in 2001, while in 2013 less than half of the households are occupiers, the average percentage of household homeownership being 42.3%.

On average, 3% of workers take the bus or train to work in both census years. The school decile denotes the socio-economic position of a school's community relative to other schools throughout the country. The school decile of an area unit is calculated by the median school decile of all the schools in an area unit. Decile 1 schools are the 10% of schools with the highest proportion of students from low socio-economic communities, whereas Decile 10 schools are the 10% of schools with the lowest proportion of these students. The socio-economic deprivation indices are employed to control the differences among area units. They reflect the quality of an area unit from the most affluent (1) to the most deprived (10) levels (Atkinson et al., 2014).

4.4.3 Empirical estimation

To test the **Hypothesis,** the empirical model that demonstrates how housing unaffordability affects the spatial mismatch of *key workers'* residence locations over time is as follows:

$$ln\left(SPI_{ijt}^{Key}\right) = \rho_1 + \omega_1 ln\left(UnAff_{ijt}\right) + \varphi_{ijt} + \gamma_1 \quad (7)$$

where $ln\left(SPI_{ijt}^{Key}\right)$ is the spatial mismatch for key workers who reside in area unit i and work in location *j* at census year *t*. $ln(UnAff_{ijt})$ represents the logarithm for the measure of housing unaffordability of area unit *i* at census year *t*.

The higher the value $ln\left(UnAff_{ijt}\right)$ is, the more unaffordable the housing in the area unit. φ_{ij_t} represents other factors that attribute to the spatial mismatch. These factors include household size (*HHSIZE*), the proportion of homeowners (*HMOWN*), the median age of the population (*AGE*), the proportion of workers take the public bus or train to work in an area unit (*PUBLICTRAN*), the socio-economic position of a school (*SCHOOLDECILE*) and the socio-economic deprivation index score (*NZDEP*). And γ_1 is the error term.

According to the spatial mismatch hypothesis, the expected sign for ω_1 is positive. The more unaffordable the area unit is (i.e., higher $ln(UnAff_{ijt})$), the longer the excess commuting distance, and hence, the more severe the spatial mismatch in the residential location choices of key workers $ln\left(SPI_{ijt}^{Key}\right)$. The model is further applied to examine the effect of housing unaffordability on the spatial mismatch of two other types of workers, namely financial and insurance workers, and retail sales workers.

4.5 Empirical results of spatial mismatch

4.5.1 Housing unaffordability effect on the spatial mismatch of key workers

Table 5 shows the estimate of spatial mismatch of key workers' due to housing unaffordability. The high housing cost relative to income ($UnAff_{ijt}$) creates a barrier to key workers in choosing where to reside. The statistically significant positive signs of ω_1 and ω_2 in column (1) and column (2) are consistent with the spatial mismatch hypothesis. Specifically, column (1) in **Error! Reference source not found.** reveals that an increase of one per cent in the mortgage repayment of annual income is expected to increase the magnitude of spatial mismatch of key workers by 0.0847 per cent and 0.0929 per cent in 2001 and 2013 respectively. This refers to an increase in excess travel distance of 2.2 km in 2001 and 2.4 km in 2013 for key workers.

Table 5 The housing unaffordability effect on the spatial mismatch of key workers

Indep. Variable/Year	(1) $ln(SPI_{2key\ workers,\ 2001})$	(2) $ln(SPI_{2key\ workers,\ 2013})$
$ln(UnAff_{2001})$	0.0847***	
	(0.0216)	
$ln(HHSIZE_{2001})$	0.165***	
	(0.0451)	
$ln(HMOWN_{2001})$	-0.155***	
	(0.0310)	
$ln(AGE_{2001})$	-0.146**	
	(0.0671)	
$ln(PUBLICT_{2001})$	0.0299***	
	(0.00400)	
$ln(UnAff_{2013})$		0.0929***
		(0.0149)
$ln(HHSIZE_{2013})$		0.0824**
		(0.0370)
$ln(HMOWN_{2013})$		-0.0959***
		(0.0177)
$ln(AGE_{2013})$		-0.248***
		(0.0460)
$ln(PUBLICT_{2013})$		0.0183***
		(0.00421)
SCHOOLDECILE incl.?	YES	YES
Constant	0.261**	0.416***
	(0.128)	(0.0906)
Observations	334	334
R-squared	0.499	0.511

Notes: Standard errors in parentheses, ***p<0.01, ** p<0.05, * p<0.1

Why this extra "two-kilometre" matters? Indeed, it is challenging to precisely pinpoint the severity of this "two-kilometre", just like it is hard to explain why the "two-degree" of global warming could be catastrophic. However, we can try to contextualise this additional "two-kilometre" by quantifying it as extra commuting costs per year associated with those key workers. The average commuting cost per person is estimated to be $0.96 per kilometre[6]. This extra "two-kilometre" could be translated into an extra commuting expense at $769 and $839 per key worker per year in 2001 and 2013 respectively. This extra "two-kilometre" spatial mismatch could result in more than $90 million loss in 2013[7]. Such translation could be underestimated given the time costs are ignored in this simple translation. The coefficients for other control variables suggest that the larger the household size, the lower the percentage of homeownership, and the younger the workforce, the more severe the jobs-housing spatial mismatch will be. Also, the positive coefficients on public transportation in both 2001 and 2013 imply that the public transportation system could not alleviate the spatial mismatch for key workers.

[6] The Ministry of Transport (2015) reports the average travel distance is 11,700 km per person per year, and Australasian Railway Association (2015) reports the annual commuting costs in Auckland is $11,227,79, thus the average commuting costs per kilometre is $11227.79/11770km≈$0.96 per kilometre.

[7] Given there are 75,108 key workers in 2001, the extra commuting expense costs $769 × 75,108 = $57,758,052; and there are 108,039 key workers in 2013, the extra commuting expense costs $839 × 108,039 = $90,644,721

4.5.2 Housing unaffordability effect on the spatial mismatch by occupations

To further appreciate the magnitude of spatial mismatch for key workers, the workers from financial and insurance (*FIN*) and retail trade (*RET*) are used to validate such spatial mismatch. Equation (12) is used to estimate the spatial mismatch among the workers in the financial and insurance as well as retail trade workers. The OLS results in Columns (1) to (4) of Table 6 demonstrate the impact of housing unaffordability on spatial mismatch across the different worker groups. The significant positive coefficients of housing unaffordability suggest that the more unaffordable the housing in an area unit, the more severe the spatial mismatch of the worker's choice of residence. This is consistent with the spatial mismatch hypothesis. Columns (2) and (3) further reveal that the housing unaffordability for both financial and insurance workers (ω_{FIN}) and key workers (ω_{KEY}) are more severe than the benchmark (ω_{BEN}), i.e., the unconstrained case choosing one's working places. The coefficients on housing unaffordability of retail trade workers (ω_{RET}) are below the benchmark. Furthermore, the significant results show that key workers face the most severe spatial mismatch compared to other workers.

To ensure the statistical difference of the coefficients of housing unaffordability for financial and insurance workers (ω_{FIN}), retail trade workers (ω_{RET}), and key workers (ω_{KEY}), the seemingly unrelated regression (SUR) is applied (Zellner, 1962). SUR is a generalisation of a linear regression model that produces more efficient estimates than OLS. More importantly, SUR gives us the capability of testing coefficients across the different equations using Chi-squared statistics. The SUR results in Columns (1) to (4) of Table 6 are similar to the OLS results. The *Breusch-Pagan* (B-P) tests for error independence indicate that the residuals in equation pairs between 1) benchmark vs key workers; 2) benchmark vs financial workers, and

3) benchmark vs retail trade workers are all positive and statistically significant and suggest that we can compare the coefficients in these seemingly related equations.

Table 6 The housing unaffordability effect on the spatial mismatch (analysed by occupations)

	OLS				SUR			
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
	$ln(SPI_{BEN})$	$ln(SPI_{KEY})$	$ln(SPI_{FIN})$	$ln(SPI_{RET})$	$ln(SPI_{BEN})$	$ln(SPI_{KEY})$	$ln(SPI_{FIN})$	$ln(SPI_{RET})$
ln(UnAff)	0.0626***	0.0929***	0.0850***	0.0534*	0.0626***	0.0929***	0.0850***	0.0534*
	(0.0160)	(0.0149)	(0.0259)	(0.0298)	(0.0154)	(0.0143)	(0.0250)	(0.0287)
ln(HHSIZE)	-0.0607	0.0824**	-0.0701	0.0751	-0.0607	0.0824**	-0.0701	0.0751
	(0.0398)	(0.0370)	(0.0646)	(0.0743)	(0.0383)	(0.0357)	(0.0623)	(0.0716)
ln(HMOWN)	0.0398**	-0.0959***	0.0287	0.0446	0.0398**	-0.0959***	0.0287	0.0446
	(0.0190)	(0.0177)	(0.0308)	(0.0355)	(0.0183)	(0.0170)	(0.0297)	(0.0342)
ln(AGE)	-0.278***	-0.248***	-0.323***	-0.388***	-0.278***	-0.248***	-0.323***	-0.388***
	(0.0494)	(0.0460)	(0.0803)	(0.0924)	(0.0476)	(0.0444)	(0.0774)	(0.0890)
ln(PUBLICT)	0.0114**	0.0183***	0.0343***	0.0446***	0.0114***	0.0183***	0.0343***	0.0446***
	(0.00452)	(0.00421)	(0.00735)	(0.00845)	(0.00436)	(0.00406)	(0.00708)	(0.00814)
Constant	0.490***	0.416***	0.576***	0.623***	0.490***	0.416***	0.576***	0.623***
	(0.0972)	(0.0906)	(0.158)	(0.182)	(0.0937)	(0.0873)	(0.152)	(0.175)
NZDEP (if incl. YES/NO)	YES	YES	YES	YES	YES	YES	YES	YES
SCHOOLDECILE (if incl. YES/NO)	YES	YES	YES	YES	YES	YES	YES	YES
Breusch-Pagan Test								
Chi-q stats: (H_0)								
$\beta_{BEN} = \beta_{KEY} = 0$						3.14*		
						(0.0766)		
$B_{BEN} = \beta_{FIN} = 0$							1.91	
							(0.1611)	
$B_{BEN} = \beta_{RET} = 0$								0.10
								(0.7543)
Observations	334	334	334	334	334	334	334	334
R-squared	0.239	0.511	0.250	0.260	0.239	0.511	0.250	0.260

Comparing the coefficients of *UnAff* among key workers to the benchmark, the spatial mismatch of key workers due to housing unaffordability is much more severe than that of the benchmark cases (i.e., in which workers are assumed to be more flexible in adjusting their workplace). Apart from the benchmark case, we have set out two other working population groups to compare the spatial mismatch of key workers. When we compare the magnitude of the unaffordability-induced spatial mismatch (i.e., coefficients of *UnAff*) of key workers (SPI_{KEY}) with that of financial workers (SPI_{RET}), it shows that such mismatch for key workers is slightly higher than that of retail sales workers, with a statistical significance level at 10%. The coefficient equality test between $UnAff_{KEY}$ *versus* $UnAff_{RET}$ gives a significant Chi-square statistics). Intuitively, retail trade workers are more flexible in adjusting their workplaces. Their housing-induced spatial mismatch should be less severe when compared to key workers. Besides, the comparison of coefficients (*UnAff*) between key workers and financial workers further reinforces the argument. Given that financial workers typically work in banks, these are likely to have fixed locations (at least fewer choices of workplaces than retail sales). In this case, the housing unaffordability-induced spatial mismatch should be similar to that of key workers but less severe than that of retail sales workers.

4.6 Remarks on spatial mismatch and housing affordability of key workers

4.6.1 Limitations

Several limitations exist in this chapter, mainly due to the data limitations and the data quality concern in the 2018 census in New Zealand. As one may be aware, this chapter only considers two waves of census data, including the 2001 census and 2013 census, and does not include the 2018 census in my analysis for several reasons. First, Statistics New Zealand had delayed its release of the main results for the 2018 census three times due to the "digital first" strategy failing to achieve a reliable response rate. In 2018, Statistics NZ urged New Zealanders to complete their census forms online, with old-fashioned paper versions seen as second best. Second, there are data quality concerns of the 2018 census as the collection response rate for the 2018 census was much lower than expected. The press release from Statistics NZ suggests that interim calculations show that full or partial information for at least 90 per cent of individuals was received, compared with 94.5 per cent for the 2013 Census. This is the lowest participation rate in more than 50 years (Stats NZ, 2019). Many economists and statisticians in New Zealand have explained the growing awareness of the severity of the "shambolic" census operations. For example, University of Auckland statistician Andrew Sporle is quoted saying: "It's a bit of a disaster, we don't know how bad, but we know it's a disaster." The data quality concern prevents us from adding the 2018 census into the current study. Third, another issue that hinders us from including the 2018 census is the new geographic boundaries applied to the 2018 census, which differed from all previous censuses (Stats NZ, 2017). The 2018 census introduced statistical area 1[8] (SA1) and statistical area 2 (SA2), while the previous census used meshblock and area units. The new geographic boundaries impede us to have a like-with-like comparison of the excess travel distance in the 2018 census.

4.6.2 Conclusion

Using census data from Statistics New Zealand in 2001 and 2013 and the spatial data of job locations, I estimated the magnitude of job-housing mismatch for key workers and explored whether housing unaffordability worsens the spatial mismatch of key workers in Auckland. By calculating the changes in key workers residential location and the housing

[8] The statistical area 1 dataset for 2018 Census replaces the meshblock dataset released in previous censuses. Meshblocks remain the smallest geographic unit but are no longer a standard output geography

affordability, some Auckland metropolitan areas with high housing costs have been exhibiting a declining trend in key worker population, whereas the suburban area's key workers population has continued to grow. This chapter reveals that the residential locational choice constraints caused by housing unaffordability significantly impact key workers' residential location choices. In particular, the deteriorating housing affordability is worsening the jobs-housing mismatch. The results also indicate that the spatial mismatch of key workers has been aggravating over the past decade, which could be attributable to the severe housing unaffordability. Such job-housing mismatch entails exorbitant social costs with more than $90 million of social loss per year in terms of extra transportation costs for key workers in Auckland. This chapter opens a future research agenda for other metropolitan cities to examine the spatial mismatch in terms of occupation groups, especially for the workers with relatively low employment turnover and the fixed workplace. The sub-optimal residential location choices likely distort their job-housing locational match, and the excess travel distance (and the associated social costs) due to deteriorating housing affordability is enormous.

In terms of theoretical contribution, this chapter has contributed to spatial mismatch literature in several ways. First, this chapter is the first study to theorise the concept of spatial mismatch hypothesis in relation to occupational groups. Much research to date on the topic of spatial mismatch focuses on demographics, skills and gender, but less is known about the effects of occupational characteristics. Second, this chapter develops a new measure to examine the degree of a spatial mismatch at an aggregate level. The measure is novel in the sense that it uses a bottom-up approach to construct a travel distance matrix that captures the excess commuting distance of all possible working and living locations for different occupational groups. Other occupation groups are used as a benchmark to underscore the severity of spatial mismatch for key workers. The results reveal that key workers are facing the most severe spatial mismatch compared to retail trade workers and financial and insurance workers. The new measure allows us to consider changes in workplaces and improvements to the public road network. This approach is expected to have a wide range of applications and could be extended to analyse other types of workers.

In terms of policy implications, the findings of the chapter suggest that improving housing affordability would help alleviate the spatial mismatch, particularly for key workers. This chapter implies that when policymakers address housing affordability issues and seek to mitigate the problem of sub-optimal residential locational choices, they should consider the transportation infrastructure and site selections of affordable housing developments to alleviate the problem of sub-optimal residential locational choices and reduce extra social costs. In New Zealand, policymakers increasingly recognise the importance of improving housing affordability. The existing National Policy Statement on Urban Development aims to loosen the constraint of height and density of buildings in the city centre and to support flexibility for both locations and land use. The Statement is expected to benefit low socio-economic groups and to improve housing affordability. Regrettably, key workers seem to be neglected when discussing target groups that benefit the most from urban land planning and new homes development.

Considering the urban economic and development, the results imply that key workers should be taken into account as the priority of policymaking. In particular, the recent Covid-19 pandemic has underscored the importance of my findings. While work-from-home is feasible for many occupations, essential services still require fixed workplaces. This chapter highlights the necessity of providing more financially affordable and spatially accessible housing for key workers. The findings emphasise that many current affordable housing programmes such as "rent-to-buy" housing and shared equity program, to name just two, need to review the job locations and commuting distance of various occupational groups. Future transportation policies should also consider the commuting infrastructure from the housing affordability perspective. The $90 million per year loss in social costs associated with housing-induced spatial mismatch always reminds us to solve "The Problem of Social Costs" (Coase, 1960), we have to analyse the costs of action involved.

Chapter 5

Household Residential Location Choices Under Uncertainty

This chapter examines the residential location choices of households with multiple potential breadwinners. In a household, each wage earner can have at least two possibilities of arranging their jobs. One potential earner may work a highly paid job with rigid work hours and a fixed workplace. Another may be able to flexibly determine their workplace and work hours. By extending Crane 's(1996) residential locational choice model, this study develops a two-worker, two-period, two-centre (2W×2P×2C) model to demonstrate the optimal residential location choices in multiple worker households. Using the Integrated Data Infrastructure (IDI) from Statistics New Zealand, empirical tests of the 2W×2P×2C model suggest that multiple worker households are less inclined to pay a rental premium to live close to the city centre compared to single-worker households. To further understand how the characteristics of individual wage earners affect their residence choices under uncertainty, their rigidity of job locations and work hours are analysed. The granular analysis confirmed the theoretical prediction that key workers with more rigid job locations are less willing to pay a higher rent to live close to the city centre. In contrast, workers taking public transport or working long hours prefer to pay a premium to reside in city centres, thus enabling less commuting and more job opportunities. These findings imply that uncertain job locations and commuting play a fundamental role in determining residential location choices.

5.1 Introduction

Residential location choice is an integral part of city planning. Residential location choices determine the demand for community facilities and services and are therefore a driving force in urban dynamics. They are also intertwined with the socio-economic development, employment market, residential segregation and transportation of a city. In urban economics, household residential location choice is considered to be a function of a wide range of housing and location attributes concerning household preferences and characteristics (Rosen, 1974; Sermons & Koppelman, 1998). Glaeser et al. (2008) explained that low-income households choose to live in the city centre because of the accessibility of public transportation. However, many standard urban economic models assume that a household has only one breadwinner and that workers never have a chance to moonlight (Highfill et al., 1995) or think about their next job (Crane, 1996). In reality, the choice of residence is more likely based on not only one particular wage earner in a household but on multiple wage earners who expect their future jobs may change and hence result in residential moves.

Among various factors that influence residential location choices, relatively few empirical studies explore how the individual characteristics of wage earners in a multiple worker household affect residential location choices under conditions of uncertainty. Unlike the conventional urban economic models that assume single-worker households, Crane (1996) put forward a theoretical two-period, two-workplace (2W×2P) model and argued that job location uncertainty would result in higher commuting costs. Later, Parenti & Tealdi (2019) empirically confirmed that workers with temporary employment contracts commute further than permanent contract workers because their next-job locations are more uncertain. Nevertheless, Parenti & Tealdi (2019) did not explicitly consider residential location choices. While many studies have indicated that when there are multiple workers are in a family, their choices of residential location are not necessarily close to the particular workplace of one household member (Curran et al., 1982; Fanning Madden, 1981; Freedman & Kern, 1997; Hotchkiss & White, 1993; Kim, 1995; Timmermans et al., 1992; Ommeren et al., 1998; White, 1999; Yiu & Tam, 2007). Yiu (2011) also argued that households with multiple earners would choose to live in commuting-convenient centres to minimise commuting costs amongst all the workers in the household.

This chapter empirically tests the relationship between the number of working family members and their residential location choices relative to the city centre. Amongst these multiple-worker households, we further test the effects of individual characteristics on their residential location choices, including (1) the effect of job location uncertainties (tested by comparing key workers to non-key workers); (2) the effect of commuting preferences (tested by comparing private versus public transport users); and (3) the effect of work hours (tested by comparing workers with long work hours to those with short work hour).

This chapter extends Crane's (1996) model to develop a two-worker, two-period, two-centre (2W×2P×2C) model on a linear city (Hotelling, 1929) and hypothesise the impact of (a) multiple commuters in a household, (b) job location uncertainties (i.e., probability of changing job locations), and (c) the household's transportation cost (i.e., distance to the city centre) on their residential location choice. Crane's model is based on the probability of a change in a job from one location to the other. We introduce job location uncertainty into the model by comparing key workers with non-key workers. While there is no universal definition of 'key worker', 'essential worker' and 'frontline service provider' are used interchangeably in local or city-specific contexts (Xiong et al., 2021).

Often, key workers can be defined as the cohort of low- to moderate- income earners who work in the public sector and provide essential services to the functioning and liveability of cities (Gilbert et al., 2021). In the context of New Zealand, a key worker is defined as an employee who provides essential services, especially in the police, health or education sectors, whose job location certainty is higher than that of non-key workers. We further assume an exponential function of transportation cost with respect to commuting distance and examine the residential location choices of two different types of commuters, namely (1) workers with long work hours; and (2) workers who have their own cars. This chapter hypothesises that these two types of commuters will have a faster rate of increase in their transportation cost function such that they are more willing to pay for living closer to the city centre.

Two waves of micro-level household census data in 2013 and 2018 from the Integrated Data Infrastructure (IDI) of Statistics New Zealand (StatsNZ) are utilised to analyse individual willingness-to-pay rents at different distances from the city centre of Auckland. The Auckland housing market is chosen as the case for two main reasons. First, the geographical relationship between the city centres, Auckland and Hamilton, 120 kilometres apart, come close to a linear form (Hotelling, 1929). Auckland is a bigger city than Hamilton, but Hamilton is more connected to other major cities, including Wellington City, the country's capital. Second, the availability of the micro-level Integrated Data Infrastructure (IDI) of Statistics New Zealand enables the granular analysis for testing the hypotheses.

The baseline model confirms Alonso's (1964) downward sloping bid-rent curve from Auckland's central business district (CBD) to the city's periphery. In the baseline model, households with multiple workers exhibit a flatter housing price gradient than single-worker households, indicating that multiple-worker households are less willing to pay for living closer to the city centre. Workers in multiple-commuter households who have longer work hours prefer residing closer to the city centres. In addition, workers who drive their own vehicles to work are less keen to live closer to the city centres. Workers with more certain job locations are less likely to live near city centres. The empirical evidence of this chapter reveals that households' residence choices will be influenced by the probability of job location changes and work hours.

The chapter is structured as follows. Section 5.2 provides a literature review on factors of uncertainties that affect the residential location choice and its corresponding outcomes. Section 5.3 develops testable hypotheses based on the two-worker, two-period, two-centre (2W×2P×2C) model of household location choices. Section 5.4 describes the data used for this study and formulates the empirical model to test the hypotheses. Section 5.5 discusses the empirical results and Section 5.6 concludes.

5.2 Literature review on residential location choices

5.2.1 Review on residential locational choice

The origin of residential location modelling can be traced back to the pioneering work by von Thünen (1826) in his “isolated state” model. He pinpointed the role of transportation costs on production locations and land markets in an agricultural state. Integral to this isolated state model is the bid-rent concept, in which peasants who are the highest value bidders are willing to pay their land rent to landowners to use the land. Alonso (1964) applied this bid-rent concept to residential location decisions and considered mono-centric city development in relation to employment opportunities. Individuals and households then choose their residential locations by maximising a utility function depending on expenditure on goods, size of the land lot, and distance from the city centre.

With the discrete choice model framework introduced by McFadden (1978), early studies attempted to quantify the contribution of residential location characteristics and household characteristics to residential location choice (Guo & Bhat, 2001; Jiao & Harata, 2007; Srour et al., 2002; Weisbrod et al., 1980). The location attributes are usually classified into four categories: the built environment, socioeconomic factors, points of interest, and accessibility. Waddell (2006) found a negative impact of dwelling density on residential choice. Bürgle (2006) and Vyvere et al. (1998) suggested a negative effect of residential location choice when the location is close to main roads or railways. Pinjari et al. (2009) found that adjacent sport and recreational facilities enhance location utility and are desired by households. The household characteristics attributes refer to a household type, income, housing costs and employment. Weisbrod et al. (1980) and Zolfaghari et al. (2012) found that differences in household size had a negative impact, implying that households prefer to live in locations with similar-size households. By considering similar households within 600 meters as an explanatory variable in their location choice models, Lee et al. (2010) indicated that households were willing to reside near their children. However, as Train (2009) suggested, it is hard to model all the attributes faced by decision-makers, and often some decision-makers' characteristics are overlooked.

5.2.2 Decision making in choosing residences under uncertainty

Housing is a complex commodity and purchasing a house and deciding the residence is crucial for any household. Residence location choices carry substantial consequences for lifestyle, social networks and job opportunities. When deciding where to reside, households face various uncertainties associated with future house price changes and economic and social variables (Marsh & Gibb, 2011). Maclennan & Whitehead (1982) suggested a behavioural framework that identified seven features of the decision process related to uncertainties in the housing market, such as imperfect information, uncertain engagement in the search process, and uncertain changes in demand. However, their framework did not indicate how to measure the uncertainties of the process when residential location choices are made (Starmer, 2000).

Considering the nature of housing consumption, Yiu (2011) classified the uncertainties into four measurable factors, namely income, housing user costs, transportation costs, and neighbourhood externalities. Andrulis (1982) identified two household uncertainties, income and housing price, faced by households, and suggested that income increases would flatten a city's aggregate house price gradient. Since housing expense is almost a fixed cost in household consumption, Turnbull et al. (1991) found that uncertain housing prices would generate uncertainties in non-housing consumption. More uncertain housing consumption causes households to relocate closer to the CBD. By imposing on utility function, the principle of decreasing risk aversion to concentration (Leland, 1978), Papageorgiou & Pines (1988) pointed out that the higher the uncertainty of transportation costs, the closer the households resided between one another, resulting in a more compact city structure.

Furthermore, Turnbull (1991) estimated the effect of uncertain housing quality on residential location choice in a monocentric city model. He found that the uncertainty of housing quality would increase housing demand in the CBD. However, those studies evidenced that residential location choices under uncertainty are just based on the mathematical derivation. Although Andrulis (1982) utilised 434 observations to conduct an empirical analysis, the study analysed the effect of risk aversion on moves toward the CBD solely. The chapter estimated neither the uncertainty effect on residential location choices nor the uncertainty effect on residential mobility.

5.2.3 Uncertainty of job location, commuting modes, and work hours

According to Kan (2003), households exhibiting high or low-risk aversion will have different tendencies to change their residences. The uncertainty, however, is seldom considered in empirical studies of residential locational choices. When considering living places, workers face uncertainty in their subsequent jobs (Kan, 2002). Many studies have explored the effect of uncertainty of job location on a household's intention to move rather than on choosing where to live. Andrulis (1982) and Crane (1996) also identified the importance of the uncertainty of job locations. Nevertheless, Andrulis (1982) examined how risk aversion affects the probability of household moving by taking the uncertainty of job location into account, while Crane (1996) focused on the effects of uncertain future job location on commuting behaviour. To the best of my knowledge, there is no literature investigating the relationship between job location uncertainty and residence locational choices.

In studies of uncertain commuting behaviour, the impact of accessibility and commuting costs on residential location choice has been extensively researched, and, to maximise household utility, uncertain commuting costs will be computed according to various conditions (Bhat et al., 2002; Kim et al., 2005; Lee & Waddell, 2010; Srour et al., 2002). A few studies have clarified the uncertain commuting expenses of different commuting modes, such as private cars and public transport (Pinjari et al., 2009). To explore the impact of uncertain commuting behaviours on residential location choice, some studies have implied that since households without a car are affected differently by transportation system development, car ownership uncertainty influences where to live (Chu, 2002; Zondag & Pieters, 2005). Glaeser et al. (2008) indicated that public transportation accessibility is a significant factor that influences low-income workers to make the location decision to live in the inner city. Bürgle (2006) suggested that households without a car prefer to live in locations with high population accessibility; the study failed to differentiate the impact of uncertain commuting modes of multiple workers households and single worker households.

When considering attributes of the residential location choice of decision-makers themselves, income, social class, ethnic background and individual's preferences are usually included (Schirmer et al., 2014). Work hours seems to be overlooked. Some studies have utilised work hours as a constraint in the utility function (Freedman & Kern, 1997b; White, 1988a), but few studies have estimated the effect of the work hours. Madden (1981) studied the residential location choices of households with husband and wife and indicated that under uncertainty of work hours, residential location is primarily based on husbands' job location. He suggested that increased work hours of the husband lead to a decrease in the commuting time of both spouses.

This chapter aims to apply the notion of uncertain workplaces to residential location choices for multiple-worker households. I attempt to fill in the gap in research on the association between job location uncertainty and residential locational choices for multiple-worker households. Also, this chapter seeks to address the lack of consideration of commuting costs as proxied by long work hours on residential location choices.

5.3 Development hypotheses of residential location choices under uncertainty

Household residential location choice is a multifaceted function of household preferences that are subject to the constraints of a wide range of housing and locational attributes. When households make their residential location choices, they inevitably face uncertainties (Fu, 1995; Robst et al., 1999; Zhou, 2011). Several studies have examined the uncertainty of residence location choices (Cockx & Canters, 2020; Yu et al., 2017; Zondag & Pieters, 2005). Many studies have divided the determining factors into economic and non-economic considerations (Phe & Wakely, 2000; Rex et al., 1967). Kim et al. (2005) utilises Oxfordshire, the United Kingdom, as a case study and reveals that the uncertainty in housing status and the uncertainty of amenity values such as the quality of local schools will affect the decision-making of households' mobility and residential choice. Recent studies tend to focus on a specific group of the population (Duncombe et al., 2003; Lu, 2020; Wang et al., 2016; Zhao et al., 2017, Cheung et al., 2021). Frenkel et al. (2013) investigated 833 knowledge-workers in Tel-Aviv and concluded that knowledge workers prefer to live in the metropolitan centre and inner ring; they propose that the uncertainties of commuting time and housing price play a key role in knowledge workers' residential choices.

Crane (1996) put forward a household utility model by considering the uncertainty of future job location: he considered the probability of job location change in a two-period, two-workplace model. Based on Crane's approach, Parenti & Tealdi (2019) enhanced the model by incorporating both the probability of changing jobs and the commuting costs. This section further develops Crane's model by considering 'two-workers-with-two-workplaces' households in two periods. Intuitively, Crane's (1996) model considered a single-worker household. If the probability of changing job location is high (or, in Crane's terminology, there is uncertainty about future job locations), one would plausibly consider the commuting costs over time when deciding where to live. Indeed, in the real world, a multiple-worker household is more common than a single-worker household; residential location choice is more likely an optimisation problem among employed household members. Provided that the probability of changes in job location is subject to constraints, including the nature of the job (e.g. key workers with fixed job locations), the more pragmatic research question one should address is how these factors (multiple-worker households, job location uncertainties and work hours) affect household residential location choices.

5.3.1 The effect of multiple-worker household

Specifically, a worker who supplies inelastically a unit of labour at the commuting cost $\tau(z)$, where z is the commuting distance, is considered. Each worker enjoys income y and consumes housing h and non-housing composite goods x. On the supply side, housing is produced by competitive firms from land and capital according to the concave constant-returnsto-scale production function $h = f(L, K)$, where L is the land and K is the capital (Mills, 1967; Muth, 1969). The worker's willingness to pay for housing at each location can be summarised by a bid rent function as follows:

$$r(z, U) \in \max_{h,z} \left\{ \left\{ \frac{[y - x - \tau(z)]}{h} |U|(h, z) > U \right\} \right\} \tag{13}$$

This represents the maximum price the household can pay per unit of housing and maintain utility level *U*.

To simplify the analysis, this study utilises two-worker households in two city centres. A two-period timespan ($t = 1, 2$) has been assigned to this optimisation problem. Workers work in both periods, and the job location in the second period is uncertain. Mathematically, suppose the city is built on a narrow strip with a width equal to one unit (i.e., a Hotelling linear city, 1929); a housing unit can be found along with the whole city. There are two city centres, C_1 and C_2 respectively, with better public transportation accessibility and job opportunities than other locations. Two workers in the households live in *RL*, and commute to C_1 and C_2, respectively as shown in Figure 9

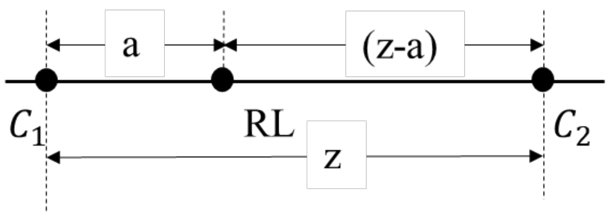


Figure 9 A linear city with two city centres

The distance between the two city centres is z. The commuting distance of one worker, $i = 1$, who travels to C_1 is *a,* while for the other worker, $i = 2$, who travels to C_2 is (*z-a*). Furthermore, the model assumes that each household inelastically supplies a unit of labour supply in their job location. The commuting costs are assumed to follow a natural exponential function, which is commuting costs, $\tau(a) = me^{w_1 a}$, where a is the commuting distance and m and w_i $(i = 1, 2)$ are constants for worker *i*. $\tau(z - a) = me^{w_2(z-a)}$ is the commuting costs for another worker in the same household who travels to C_2 with a commuting distance of (*z*-*a*). If the probabilities of workers 1 and 2 changing job location in the next period are denoted by β_1 and β_2, respectively, then the commuting cost to the household in the two periods is τ_H.

The present discount value of the commuting expenses for all the workers in the household is,

$$\tau_H = m\left[e^{w_2(z-a)} + e^{w_1 a}\right] + \delta n\left[\beta_1 e^{w_1(z-a)} + (1-\beta_1)e^{w_1 a} + \beta_2 e^{w_2 a} + (1-\beta_2)e^{w_2(z-a)}\right] \quad (14)$$

where τ_H is the total commuting costs of household members, and δ is the discount factor since we are calculating the present value of the commuting expenses. Assume that *x*, *h*, and *r* in Equation (13) are constant across the two time periods, and maximising the household's utility level, *U* needs to minimise the household's commuting costs. If the workplaces of households are certain and job location change is not considered, we only need to consider the first term at the current period. Assuming $w_1 = w_2 = w$ in the first case, the condition for minimum commuting cost is as follows:

$$\frac{\partial \tau_H}{\partial a} = mw\left[e^{wa} - e^{w(z-a)}\right] = 0;$$
$$=> a = \frac{z}{2}; \quad (15)$$

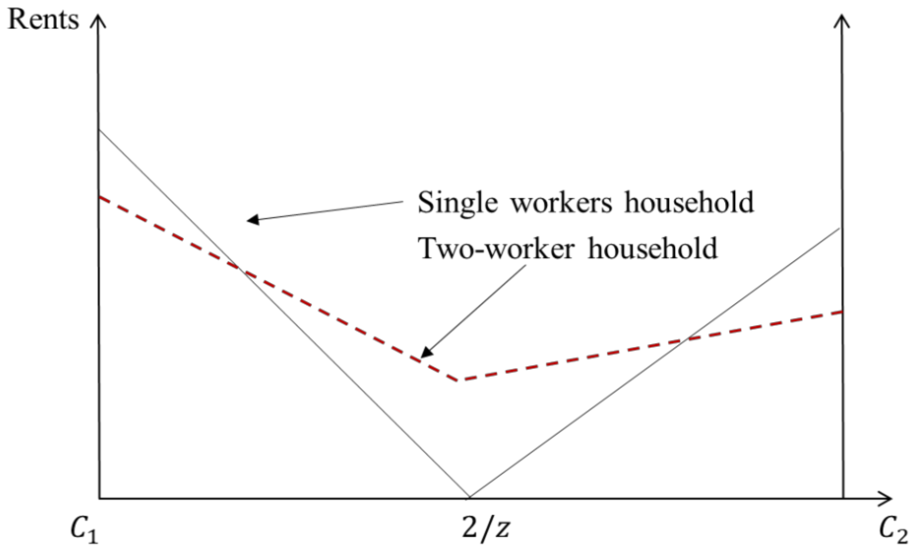


Figure 10 Price gradient for two-worker households

As shown in Figure 10, the solid line is the price gradient of a single worker household with a fixed job location at the city centre C_1.The broken line denotes the price gradient of a two-worker household with two fixed-job locations, i.e., one at the city centre C_1 and the other at C_2. When $a = z/2$, τ_H gives the minimum commuting expenses, indicating that a two-worker household will choose to live in the middle between two city centres that minimise the job and commuting uncertainties. That is, two-worker households are less willing to live closer to those two city centres. Therefore, we hypothesise that:

H1: Ceteris paribus, multiple-workers households are less willing to pay rental premiums to live close to the Auckland city centre than single-worker households.

5.3.2 The effect of job location uncertainty

Next, we extend the one-period model into a two-period model for a two-worker household in a city with two different centres. There is a probability of changing job locations in the second period. Considering that the job location is uncertain as a result of changing the job, commuting expenses will be incurred in both the first and the second periods. There are four possible scenarios: 1) both workers remain at the current job location; 2) the worker who works at C_1 switches to C_2, whereas the worker at C_2 remains at the same job location; 3) the worker who works at C_1 remains at the same location, while the worker who works at C_2 moves to C_1; and 4) both workers swap their job locations, thus the worker at C_1 changes to C_2 and the worker at C_2 switches to C_1. In the context of empirical tests in the ensuing section and without the loss of generalisability, we consider the third scenario by considering a key worker in the household who remains at the same work location, while the other worker, who works at C_2, chooses to move to C_1. For the completeness of the model, other scenarios will be analysed in the Appendix.

Suppose, in a two-worker household, that one worker is a key worker with high certainty in the job location, which means a lower probability of changing job. We assume that $\beta_1 \approx 0, \beta_2 \approx 1$, then the second term of Equation (14) will be $\delta n(e^{wa} + e^{wa})$. When two periods are considered, the commuting cost is

$$\tau_H = m\left[e^{w(z-a)} + e^{wa}\right] + \delta n\left[e^{wa} + e^{wa}\right] \quad (16)$$

To minimise the commuting expenses irrespective of the vehicle that has been used to commute, the condition is:

$$\frac{\partial \tau_H}{\partial a} = mw\left[e^{wa} - e^{w(z-a)}\right] + 2\delta nwe^{wa} = 0 \quad (17)$$

$$e^{w(z-a)} = \frac{m + 2\delta n}{m} e^{wa}$$

$$a = \frac{zw - ln\left(\frac{m + 2\delta n}{m}\right)}{2w} < \frac{z}{2} \quad (18)$$

As stated in Equation (18), when $a < z/2$, the household has the minimum commuting costs. In other words, when one worker in a household is a key worker with a low probability of changing jobs, the household prefers to live closer to the key worker's job centre.

When $a < z/2$, τ_H has the lowest commuting costs, suggesting that a two-worker household that resides near workers with a lower probability of changing jobs has the lowest commuting expenses. Two-worker households with higher uncertainty in job location are more willing to live closer to either one of the city centres. Therefore, we hypothesise that:

H2: Ceteris paribus, the workers with higher certainty in their job location (i.e., proxied by key workers) are less willing to pay a rental premium to live closer to the Auckland city centre.

5.3.3 The effect of uncertainty of commuting behaviour

Relaxing the assumption of equal weighting of the transportation cost function, the effects of commuting costs on residential location choices are investigated. The impact of commuting modes have been studied in both the transportation and the urban studies literature (Clifton et al., 2015; Guo et al., 2020; Heinen et al., 2013; Norbis & Meixell, 2008). Intuitively, workers who commute by public transport will have a higher rate of transportation costs with respect to commuting distance than commuters by private car, i.e. a higher weight *w*.

Similarly, the effects of working hours have been widely studied (Cogan, 1980; Small et al., 2005; Ommeren & Fosgerau, 2009). Workers who work long hours will have higher opportunity costs in terms of extra parking fees or not being able to use public infrastructure late at night. The rate of changes in commuting expenses through long hours workers is higher than that for normal work hours workers. The first-order condition of minimising commuting costs becomes:

$$\tau_H = m\left[e^{w_2(z-a)} + e^{w_1 a}\right] \tag{19}$$

$$\frac{\partial \tau_H}{\partial a} = m\left[w_1 e^{w_1 a} - w_2 e^{w_2(z-a)}\right] = 0 \tag{20}$$

There are two possible cases: 1) $w_2 \gg w_1$, and 2) $w_2 \ll w_1$ with different commuting costs. If $w_2 \gg w_1$,

$$\begin{gathered} e^{w_2(z-a)} = \frac{w_1}{w_2} e^{w_1 a} < e^{w_1 a} \\ a > \frac{w_2 z}{w_1 + w_2} > \frac{1}{2} z \end{gathered} \tag{21}$$

indicates that when a worker in a two-worker household has a higher rate of increase in transportation cost, say $w_2 \gg w_1$[9], the households prefer to live closer to C_2 to achieve the minimum commuting expenses. This indicates that when a worker in a two-worker household has a higher rate of increase in transportation cost, say $w2 \gg w1$, would be more willing to pay a rental premium to live closer to the job location of the worker.

Therefore, we hypothesise that:

H3: Ceteris paribus, households with higher commuting uncertainties to work (i.e., proxied by long work-hour workers who may be unable to assess proper public at night) are more willing to pay a rental premium to live closer to the Auckland city centre.

[9] The proof process when $w_1 \gg w_2$ will be provided in Appendix.

5.4 Research design to estimate residential location choices under uncertainty

5.4.1 Data

The data used in this chapter are sourced from Integrated Data Infrastructure[10] (IDI) of Statistics New Zealand (Stats NZ). The IDI is an extensive research database curated by Stats NZ. The IDI contains matched, de-identified data on people and households in New Zealand collected by Government agencies, Stats NZ surveys, and non-governmental organisations (NGOs) (Stats NZ, 2021). This chapter employs the individual-level microdata from waves of population census, including the 2013 census and the 2018 census, and meshblock [11] level data from the geographic information dataset in IDI. Figure 11 shows the Auckland region and the 100 km buffer from the Auckland city centre.

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[10] Integrated Data Infrastructure is a large research database. It holds microdata about people and households. The data is about life events, such as education, income, benefits, migration, justice, and health. It comes from government agencies, Stats NZ surveys, and non-government organisations (NGOs). The data is linked together, or integrated, to form the IDI. There are tight broad categories of data including health, education and training, benefits and social services, justice, people and communities, population, income and work, and housing in the IDI (Stats NZ, 2021b).

[11] A meshblock is the smallest geographic unit for which statistical data is collected and processed by Stats NZ. A meshblock is defined by a geographic area, which can vary in size from part of a city block to a large area of rural land. Each meshblock borders on another to form a network covering all of New Zealand, including coasts and inlets and extending out to the 200-mile economic zone

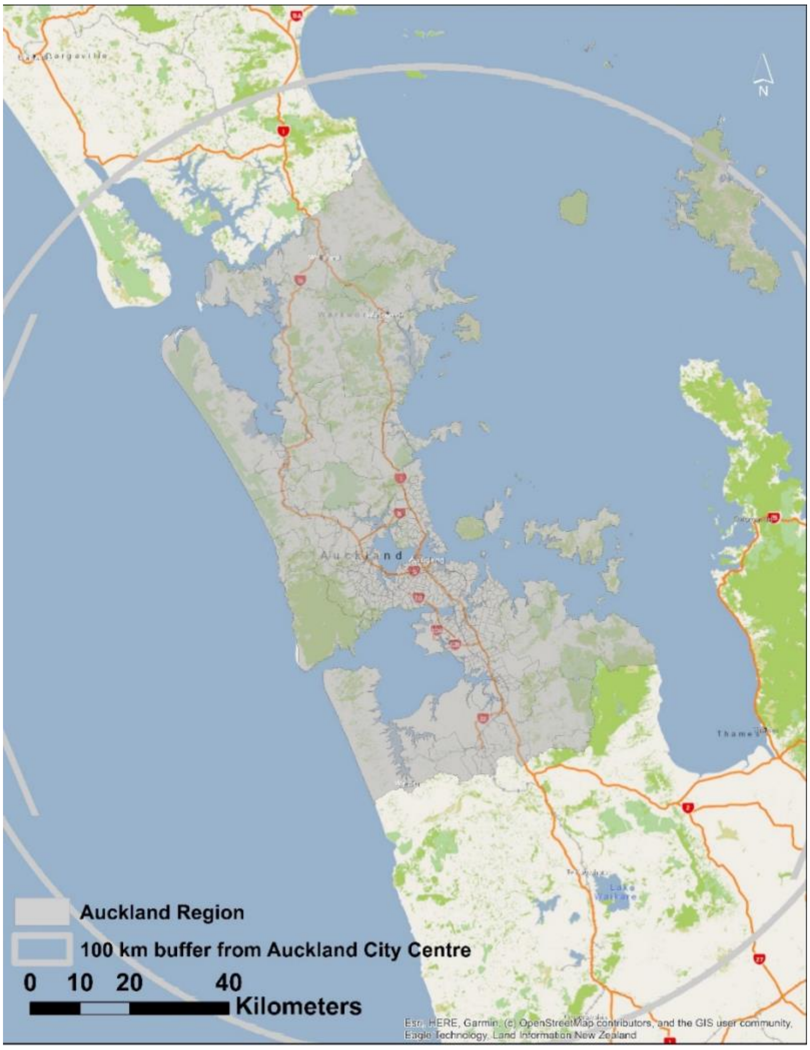

Figure 11 The Auckland region and the 100 km buffer from Auckland city centre

The distinct advantage of IDI data is that the matched micro-level data of individuals allows us to see the compounding and interrelated factors that affect people's lives and needs at a far more nuanced level and to measure outcomes for population cohorts over time. To satisfy the pre-condition of the hypotheses, the dataset consists of workers in households with no more than three workers. Also, we consider only workers who are renters in privately-owned housing in Auckland. Table 7 shows the descriptive statistics of the data used, and the dataset contains 175,810 observations. The average weekly rent (r) is \$513.54 (in New Zealand dollars). The weekly rents of more than \$3000 are excluded from the analysis as outliers. The mean commuting distance (*d*) is 7.52 km. The minimum commuting distance of zero denotes that the workers work in the same meshblock where they reside, and the standard deviation of 5831 indicates that commuting distances vary across workers. Distances greater than 100 km[12] will not be considered in the study. The income bands of the income are available in the IDI census data and do not provide the particular income numbers. Therefore, I employ the midpoint of the income band as the proxy of the workers' income. The average annual income (*inc*) is $52,920, and the standard deviation of the annual income is 37,542, which suggests that the income amongst workers differs.

Table 7 Descriptive of variables and summary statistics

Description	Variable	Mean	S.D.	Min	Max
Weekly rents amount *(NZD)*	*r*	513.54	183.42	1.00	2,858
Direct distance (in m) from population centroid of home meshblock to city centre	*d*	7520.51	5830.82	0.00	67754.71
Annual income *(NZD)*	*inc*	52920.35	37542.21	1000.00	213000.00
Numbers of bedrooms	*bdrm*	3.13	1.02	1.00	14.00
Numbers of heating	*fuel*	1.17	0.67	0.00	7.00
Numbers of vehicles	*veh*	2.04	1.00	0.00	9.00
Time dummies for census year	*year*	0.62	0.49	0.00	1.00
Dummy variables of key workers	*keywk*	0.10	0.30	0.00	1.00
Main job work hours	*wkhr*	37.72	12.61	1.00	152.00
Deprivation Index of New Zealand	*NZDep*	5.48	2.73	1.00	10.00
Dummy variable of ethnicity					
Asian	*asian*	0.22	0.42	0.00	1.00
European	*euro*	0.59	0.49	0.00	1.00
Maori	*maori*	0.05	0.23	0.00	1.00
MEA	*mea*	0.03	0.16	0.00	1.00
Pacific	*paci*	0.09	0.29	0.00	1.00
Others	*other*	0.01	0.11	0.00	1.00

Note: Total number of observations is 175,810.

[12] Figure 11 presents the 100 km buffer from the Auckland city centre. The area covers the entire Auckland and part of the Hamilton, and this range of distance can indicate the gradient change between these two centres.

The average number of bedrooms (*bdrm*) is approximately three while the numbers of heaters in a household used are more than one. The dummy variable of census year (*year*) equals 1 when the observation comes from the 2018 census and 0 when the observation belongs to the 2013 census. The key workers are seven occupations: teachers, nurses, firefighters, health workers, child carers, personal carers and police, according to the Australian and New Zealand Standard Classification of Occupations[13] (ANZSCO). The key worker dummy variable (*keywk*) is 1 when the worker's occupation belongs to the groups above, or otherwise 0.

The New Zealand Index of Deprivation is an area-based measure of socioeconomic deprivation (Atkinson et al., 2019). It measures the level of deprivation of people in each small area. It is based on nine Census variables. NZDep is displayed in deciles. Each NZDep decile contains about 10% of small areas in New Zealand. Decile 1 represents areas with the least deprived scores, whereas decile 10 represents areas with the most deprived scores. In general, people who live in more deprived areas (for example, NZDep2018 decile 9 and 10) are more susceptible to environmental risks. They may also have less capacity to cope with the effects of environmental risks and fewer resources to afford good quality housing or heating for their family. The ethnicity dummy includes European, Asian, Maori, middle eastern (MEA), Pacific, and others. Moreover, working hours that exceed 168 hours will be not considered in the estimation and the average work hours are 37.72 while the maximum work hour is 152 hours, implying that some workers work extensive hours. Table 8 shows the average distance-to-CBD and rents for different groups of households.

[13] Australian and New Zealand Standard Classification and Occupations (ANZSCO) was jointly developed by the Australian Bureau of Statistics and Statistics New Zealand in order to make it easier to compare industry statistics between the two countries and with the rest of the world (available at: https://www.immigration.govt.nz/new-zealand-visas/apply-for-a-visa/tools-and-information/work-and-employment/full-occupation-list)

Table 8 Description of the average distances to CBD of various groups of households

	DTC(distance to CBD)/km	Rents/$ NZD
single-worker households	7.9	477.99
multiple-worker households	7.33	531.51
key workers households	7.95	487
non-key workers households	7.47	516.37
using private vehicle households	8.06	509.23
not using private vehicle households	5.27	527.78
short-work hours households	7.48	508.27
long-work hours households	8.00	541.32

5.4.2 Empirical model

The empirical analysis is divided into two stages. In the first stage, I estimate Alonso's (1964) bid-rent curve in Auckland, and the effect of numbers of workers in the household choosing residence will be estimated. In the second stage, the main objective is to examine how the residential location choice will be affected when taking into account (1) the certainty of job locations and (2) the work hours, of multiple-worker households.

In the first stage, to confirm the bid-rent curve in Auckland, and to test how the numbers of workers in the household change the curve, I specify the following Equation:

$$ln(r) = \alpha_k + \beta'_k wknu_k + \beta_k wknu_k \times ln(d) + \gamma_k \, ln(d) + \omega_k year + \delta_k \, ln(\boldsymbol{X}) + \varepsilon_k \quad (22)$$

where ln(r) is the natural logarithm of weekly rents paid by workers. *ln(d)* denotes the natural logarithm of commuting distance from individual living places to the city centre[14]. $\boldsymbol{X}$

[14] City centre is defined as the mesehblock code equals to 0433801. The x-coordinate of population centroid of this meshblock is 1757068.17349343, while y-coordinate of population centroid of this meshblock is

is a vector of control variables, including numbers of bedrooms ($bdrm$), numbers of heating (*fuel*). New Zealand Index of Deprivation (NZDep*,* 2018) is an area-based measure to control socioeconomic deprivation in New Zealand. ε is the error term.

To test **H1**, $wknu_k$ is a set of dummy variables that denotes that there are k workers in the household. When k equals 2, $wknu_2$ equals 1, indicating that the workers belong to a two-worker household and that the two workers in one household have different workplaces; otherwise, it equals 0. When k equals 3, $wknu_3$ equals 1, implying that the workers belong to a three-worker household, and the three workers in one household could have two or three workplaces; otherwise, it equals 0. This baseline model is used to demonstrate Alonso's bid-rent curve in Auckland, the coefficient of γ_k is expected to be negative, and if the effect of the numbers of workers in a household of **H1** is confirmed, the coefficient of β_k is expected to be positive ($\gamma_k < 0$, $\beta_k > 0$). This will mean that workers in multiple-worker households are less willing to pay a rental premium to live closer to the city centre.

$$ln(r) = \varphi_i + \tau'_{H_i}H_i + \tau_{H_i}H_i \times ln(d) + \theta_i \, ln(d) + \mu_i year + \sigma_i \, ln(K_i) + \epsilon \qquad (23)$$

In the second stage, only multiple-worker households are examined. We confine the sample to multiple-worker households in which the workplaces of the workers in households are far apart to estimate how (1) the uncertainty of job locations and (2) work hours affect the residence choices of workers in such households, Equation (23) is constructed, *where* K_i is a vector of control variables, including annual income (*inc*), bedroom (*bedr*) and numbers of heating (*fuel*) and quantity of vehicles (veh). ϵ is the error term.

5920424.94990075 in 2013. The x-coordinate of population centroid of this meshblock is 1757068.17304683 and the y-coordinators population centroid of this meshblock is 5920424.95217659 in 2018.

H_i are the variables for testing the corresponding hypotheses. To test **H2**, an indicator variable $\boldsymbol{keywk}$ is specified. If the worker's occupation belongs to the key worker group this indicator equals 1; otherwise, it is 0. Non-key workers are more uncertain about their workplace. As a result, non-key workers are more inclined to pay a higher rent to live in city centres than are key workers. The interaction term of $\boldsymbol{keywk} \times ln(d)$ is introduced to test the moderating effect on distance. Given the higher certainty of job location of key workers, they should have a positive moderating effect on commuting distance (*ln(d)*), hence a negative impact on weekly rents (*ln(r)*). If the moderating effect mentioned in **H2** is confirmed, the coefficient τ_{H_1} is expected to be positive ($\tau_{H_2} > 0$). This means that non-key workers are more willing to pay high rent to live in the city centres.

To test **H3**, *wkhr* is a continuous variable of work hours that a worker commits each week. Intuitively, workers who have extensive work hours will have less leisure time and a stronger desire for living convenience. The convenience of living refers to having easy access to various daily requirements, such as shopping, leisure, and commuting (Tian et al., 2018). City centres are usually acknowledged as the area where proximity to services, amenities and public transport is greatest (Buys & Miller, 2011). Thus, considering the uncertainty of work hours, long work hours workers prefer to reside in the inner city and pay a higher rent. Given **H3** is confirmed, the coefficient of interaction term of $\boldsymbol{ln}(\boldsymbol{wkhr}) \times ln(d)$ is expected to be negative (τ_{H_3}<0). When workers make decisions on residence location under the uncertainty of work hours, this indicates that workers with extensive hours per week are more inclined to live closer to the city centre and pay a higher rent.

5.5 Empirical results of residential location choices under uncertainty

5.5.1 Single-worker household vs multiple-worker households

Table 9 shows the results relating to the bid-rent curve in Auckland. Column (1) shows the bid-rent curve in Auckland regardless of the numbers of workers in one household. The coefficient of distance to the city centre (*ln(d)*) is -0.06, indicating that a one per cent change in living distance from the city centre leads to a 0.06 per cent decline in weekly rents. This suggests that every 0.08 km increase from the city centre is associated with an approximately $0.3 decrease in the weekly rents. It confirms the downward sloping bid rent curve from the city centre. The coefficients of other control variables also meet the expectations. The positive sign of bedroom (*bdrm*) and numbers of fuel (*fuel*) suggest that the more the bedrooms and the numbers of fuels, the higher the rents. The positive sign of years (*year*) indicates that the rents in 2013 are higher than the rents in 2001.

Table 9 Bid-rent curve of multiple-work household in Auckland

	(1)	(2)	(3)
	baseline	multiple workers household	multiple workers household
	ln(r)	*ln(r)*	*ln(r)*
dummy variables of workers:			
2 workers household [1,0]		0.0459**	0.0151*
		(0.0018)	(0.0131)
3 workers household [1,0]		0.0806***	0.0698***
		(0.0023)	(0.0166)
2 workers household [1,0] × *log(d)*			0.0036**
			(0.0015)
3 workers household [1,0] × *log(d)*			-0.0013
			(0.0019)
log(d)	-0.0608***	-0.0592***	-0.0611***
	(0.0007)	(0.0007)	(0.0166)
log(bdrm)	0.6177***	0.5909***	0.5909***
	(0.0032)	(0.0033)	(0.0033)
log(fuel)	0.0127***	0.0137***	0.0136***
	(0.0026)	(0.0026)	(0.0026)
year [1,0]	0.2367***	0.2327***	0.2327***
	(0.0017)	(0.0017)	(0.0017)
constant	5.8661***	5.8560***	5.8721***
	(0.0081)	(0.0081)	(0.0113)
NZDep (1 - 10) 1 as the base	YES	YES	YES
Observations	175,810	175,810	175,810
R-Squared	0.2889	0.2942	0.2942

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

Columns (2) and (3) demonstrate the results of Equation (22), which tested the bid-rent curve of multiple-worker households in Auckland. In column (2), the coefficients of the two-worker household dummy variable (β'_2) and three-worker household variable (β'_3) are 0.0459 and 0.0806, respectively. The results imply that the weekly rent of workers in two-worker and three-worker households is about 4.6% and 8.1% higher than in single worker households. The interaction term of two-worker household and distance to the city centre (β_2) is significantly positive, confirming the first hypothesis that workers in two-worker households are less willing to pay a rental premium to live closer to the city centre. Interestingly, the coefficient of the interaction term for workers in three-work households (β_3) is insignificant. This may be due to the limited supply of housing for three-worker households in the inner city.

Table 10 presents the analysis of the stage two tests that confine the dataset to multiple-worker households only. It shows the results of Equation (23), which estimated how the uncertainty of job locations (non-key workers) and work hours influence the residence choice of multiple-worker households.

5.5.2 Uncertainty of job location and commuting behaviour

Columns (1) and (2) show the results of H2 for Equation (23). Column (1) indicates that the coefficient of key worker dummy (τ'_{H_2}) is -0.0294. This denotes that non-key workers are paying 2.9% more in rent than their counterparts. Column (2) shows the results for key workers at an individual-level. The interaction term coefficient (τ_{H_2}) is positive and significant, which means that key workers are less willing to pay a rental premium to live closer to the city centre than non-key workers. These results confirm the **H2**, suggesting that non-key workers are more willing to live closer to the city centre. Column (3) to (4) illustrates how long work hours workers have their residential location choices. Given the long work hours, works are more uncertain about their jobs (i.e., their job location, the night shift arrangement, the uncertain access to public transportation, and fluctuating work hours etc.), all these will trigger the long work hour workers to intend paying more to live nearby the city centre. The work hours coefficient (τ_{H_3}) is -0.0146, which is significantly negative, which implies that workers of longer work hours pay less in the weekly rents to live at the city centre (when d=0). The coefficient of the interaction term *ln(wkhr)×ln(d)* is significantly negative (steeper slope of the bid-rent curve), which confirms that workers of longer work hours are more willing to pay a rental premium to live closer to the city centre. These results confirm **H3**.

Besides, the coefficients of income (inc) are significantly positive across column (1) to column (4), suggesting the higher the income of the workers, the higher the rental prices. The income of the workers will have a positive effect on the rental price. Likewise, the number of bedrooms will have positive impact on the rents, higher rents are associated with more bedrooms. It is interesting to note that coefficients of fuel numbers are negative from column (1) through column (4), even though the results are insignificant, it implies that increasing the numbers of fuels in the property, the rents will decrease. It may be due to properties with a large number of fuels usually are older properties; older properties typically have higher fuel expenses and the rents will relative lower. The numbers of vehicles have a positive effect on the rents, indicating the workers associated with more numbers of vehicles tend to have a higher rents. And the coefficients of year dummy (*year*) are positive through four columns indicates that the rents are higher in 2018 than in 2013.

One may question whether the effect of commuting modes matters. To control the impact of commuting modes, a sub-sample of workers using private vehicle have been used to estimate Equation (23) as a robustness check. Columns (5) and (6) of Table 10 illustrate the effect of work hours on residential location choice. With those workers taking private vehicles, the coefficient of the interaction term $ln(wkhr)\times ln(d)$ remains significantly negative. This implies that the workers who are using private cars with have long work hours (therefore less uncertain than those taking public transport) are still more willing to pay a rental premium to live closer to the city centre. The results further confirm the H3 as a robustness test.

Table 10 Effects of uncertainties for non-key workers and work hours o price gradient of multiple-worker households

	(1)	(2)	(3)	(4)	(5)	(6)
	H2: Fix Location	H2: Fix Location	H3: Long Work Hours	H3: Long Work Hours	H3' Long-hour with Private car	H3' Long-hour with Private car
	ln(r)	*ln(r)*	*ln(r)*	*ln(r)*	*ln(r)*	*ln(r)*
keywk[1,0]	-0.0294***	-0.1110***				
	(0.0031)	(0.0247)				
keywk × ln(d)		0.0095***				
		(0.0029)				
log(wkhr)			-0.0146***	0.0278**	-0.0119***	0.0569***
			(0.0023)	(0.0138)	(0.0029)	(0.0194)
log(wkhr) × ln(d)				-0.0050***		-0.0080***
				(0.0016)		(0.0022)
ln(d)	-0.0593***	-0.0601***	-0.0594***	-0.0416***	-0.0547***	-0.0258***
	(0.0009)	(0.0009)	(0.0011)	(0.0058)	(0.0011)	(0.0081)
ln(inc)	0.0266***	0.0266***	0.0308***	0.0307***	0.0357***	0.0356***
	(0.0010)	(0.0010)	(0.0012)	(0.0012)	(0.0015)	(0.0015)
ln(bdrm)	0.5621***	0.5621***	0.5614***	0.56147***	0.5683***	0.5686***
	(0.0042)	(0.0042)	(0.0042)	(0.0042)	(0.0049)	(0.0049)
ln(fuel)	-0.0036	-0.0035	-0.0042	-0.0043	-0.0056	-0.0057*
	(0.0030)	(0.0030)	(0.0030)	(0.0030)	(0.0035)	(0.0035)
ln(veh)	0.0514***	0.0516***	0.0516***	0.0514***	0.0669***	0.0669***
	(0.0031)	(0.0031)	(0.0031)	(0.0031)	(0.0040)	(0.0040)
year [1,0]	0.2250***	0.2249***	0.2248***	0.2248***	0.2194***	0.2194***
	(0.0020)	(0.0020)	(0.0020)	(0.0020)	(0.0023)	(0.0023)
constant	5.5993***	5.6063***	5.6064***	5.4572***	5.4811***	5.2343***
	(0.0142)	(0.0144)	(0.0143)	(0.0500)	(0.0186)	(0.0712)
Ethnicity (i.e., European, Maori, MEA, Pacific, Asian, Others) - Asian as the base	YES	YES	YES	YES	YES	YES
NZDep (1 - 10) - 1 as the base	YES	YES	YES	YES	YES	YES
Observations	116,772	116,772	116,772	116,772	84,907	84,907
R-Squared	0.3005	0.3006	0.3002	0.3002	0.3046	0.3047

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

5.6 Remarks on household residential location choices under uncertainty

Research on the residential location choice of households has typically assumed a single breadwinner, and high certainty in job location, the nature of employment and household characteristics (Madden, 1981; Johnsen, 2020; Madden, 1980; Timmermans et al., 1992; Van Ommeren et al., 1998). This chapter explores how individual characteristics influence where households choose to reside by considering the possibility of individuals changing their jobs, work hours and commuting mode. By extending Crane's (1996) framework, a two-worker, two-period, two-centre (2W×2P×2C) model is developed on a linear city to estimate the impact of job location uncertainties and commuting costs on the residential location choices of multiple-worker households.

The data is obtained from the Integrated Data Infrastructure of Statistics New Zealand, which identified single-worker and multiple-worker households with different job locations. As evidenced in this chapter, workers in multiple-worker households live further from the city centre than do workers in single-worker households. The results suggest that households with non-key workers, who are relatively less certain about their job locations, would prefer to live closer to the city centre and pay 3.3% more rent than key workers. In addition, the findings indicate that workers who commute by public transportation are less willing to live closer to the city centre. They pay 3% more in rent than workers who use private automobiles. In other words, the result implies that households with workers who work long hours prefer to live closer to the Auckland city centre.

The contributions of this chapter are as follows. Theoretically, this chapter developed a two-worker, two-period, two-centre (2W×2P×2C) model based on Crane (1996). Using two waves of census data, the model shows that the household residential location choices are made jointly by workers in a household. Multiple-worker households are more willing to live further away from the city centres than single-worker households. The model for this study also estimates the effects of uncertainty of job locations and commuting costs on residential location choices. More interestingly, some light is shed on the role of job location uncertainty and work hours differences in the residential location choices of multiple-worker households. While in the literature, only the household characteristics of single-worker households are examined, in this paper, other important attributes such as job location uncertainties and work hours, which have fundamental roles in residential location choices, are considered.

In terms of practice, these results are relevant to policy formulation. The findings suggest that workers who use public transport are less willing to live closer to the city centre. This seems consistent with the urban development in Auckland over the last few years, which is the Ministry of Transport of New Zealand has developed many public transport infrastructures in the outer ring of Auckland city and far away from the city centre. The policymaker could continuously improve the outer ring public infrastructure. Second, considering most households are multiple-worker households in Auckland, the results call attention to the multiple-worker households that live further away from the city centres and may lead to expansion of the city fringe. In addition, this chapter shows that key workers who have more certain job locations typically work at the public hospital and reside further away from the city centres. As a result, recruiting and retaining key workers will become an issue in Auckland.

Chapter 6

Conclusion

Amid increased housing costs and related concerns about spatial mismatches between housing opportunities and jobs, this thesis examines the effect of rising housing costs on the choice of residential location. A moderate-income working population, whose members are known as key or essential workers, is chosen to investigate how housing affordability affects people's choice of where they live and how they make decisions under conditions of uncertainty. More than a decade after this issue was examined by various British urban studies researchers, the significance of key workers has again come to the fore against the backdrop of the COVID-19 outbreak. At a time when working from home is on the rise, the studied population is unlikely to benefit from this emerging trend. Even worse, these workers typically earn too much to qualify for subsidised housing yet too little to purchase private housing at market prices. The final chapter of this thesis summarizes the findings and discusses this thesis's contribution to the academic discourse. The limitations of this study are also identified to guide future research. Finally, several recommendations and implications of this thesis are discussed.

6.1 Summary of findings and contributions

This thesis examines residential location choice under constraints of housing affordability for different occupations amid conditions of uncertainty. This chapter summarises this thesis's main findings and contributions.

6.1.1 Model of household residential locations under uncertainty

The first contribution of this thesis is to further develop the two-worker, two-period, and two-centre residential location choice model under conditions of uncertainty. Crane (1996) developed a two-period, two-centre model of residential location choice under certainty but focused on how uncertain future job location affects commuting behaviour and presented only theory development and mathematic calculations without conducting empirical analysis. My thesis investigates the residential location choices of two-worker households under conditions of uncertainty about job location. My analysis indicates that multiple-worker households are less willing to pay a rent premium so that they can live closer to the city centre. Among these, households with highly uncertain job locations (non-key workers) reside closer to the city centre and pay 9.6% higher rent than those with more certain job locations (key workers).

6.1.2 Identification of other factors in the choice of residential location

Second, my thesis offers evidence that work hours and commute mode both affect commuting costs and play a crucial role in multiple-worker households' decisions about where to live. This finding implies that workers who commute by private automobile pay 3% less rent than those who commute by public transportation and live farther from the city centre, whereas workers who work long hours are more willing to pay a rental premium to live closer to the city centre. The previous study appears to neglect the effect of working hours on commuting costs and thus also on residential location choices.

6.1.3 Extension of the spatial mismatch hypothesis

Most of the theoretical literature on the spatial mismatch hypothesis concerns low-skilled minorities, and it focuses mainly on the United States. This thesis represents a first attempt to theorise the concept of spatial mismatch hypothesis in relation to occupational groups against the backdrop of deteriorating housing affordability in New Zealand. The third contribution of this thesis is to expand the scope of the spatial mismatch hypothesis by taking into account worker occupations and their associated budget constraints. Comparing key workers with two other worker groups and considering key workers' intrinsically greater certainty about job location, this thesis reveals that key workers are the most sensitive to increasingly expensive housing costs, whereas finance workers are the least sensitive. As a consequence, key workers suffer the longest commutes, exhibit disproportionate excess commuting and show the severest job–housing mismatch among select working populations. Furthermore, budget constraints limit key workers in Auckland to make *sub-optimal residence choices*, living farther from their workplaces and accepting longer commutes for lack of affordable residential options.

6.1.4 Excess commuting as an indicator of spatial mismatch

The fourth contribution of this thesis is its use of the excess commuting measure as an imbalance measure of spatial mismatch. Giuliano & Small (1993), Horner (2002), and Small & Song (1992) suggested that the theoretical minimum commute in the excess commuting measure could capture the degree of mixture between jobs and housing in an area. Mixed land use may decrease the theoretical minimum commute in the excess commuting measure. This thesis constructs a distance matrix at an area unit level and uses excess commuting distances as a proxy to quantify spatial mismatch and estimate susceptibility to housing unaffordability. Analysis shows that, on average, a 1% increase in the ratio of annual mortgage repayments to household income will increase spatial mismatch, evident as excess travel distance, by 0.093%, translating into 2.4 kilometres' excess travel distance for every 1% increase in housing costs.

6.1.5 Visualise commuting flow using the excess commuting measure

Last but not least, this thesis extends the concept of the excess commuting measure so as to visualise workers' commuting patterns. The spatial distribution of commuting patterns reflects various residence-related attributes, job opportunities and commuting behaviour. Urban decentralisation determines the range of urban commuting potential, so that a more dispersed city structure provides greater commuting flexibility. Job decentralisation, changes in population and public infrastructure improvements all influence absolute travel distances within urban commuting ranges. The excess commuting measure offers a way of measuring *relative* commuting distance, avoiding the problem of *absolute measures*.

Using excess commuting flows to visualise commuting flows can alleviate the cluttering problem without losing crucial information from raw data. The excess commuting approach assesses the difference between actual and theoretical minimum commuting distance to offer insights into the distribution of affordable housing and job opportunities, allowing the formulation of a city structure that balances the jobs and housing for various occupations throughout an area.

6.2 Limitations

One limitation of this thesis is that road network data and GIS-related software are not available in the IDI DataLab environment. To protect personal information, IDI DataLab does not allow researchers to map road networkers to individual addresses. Accordingly, this thesis uses Euclidean distance as the second-best solution for estimating commute distance when working with individual-level data from IDI DataLab. To overcome the limitations of using absolute commuting distance, I examine the magnitude of "excess" commuting among workers within the same occupation group who live in the same areas, comparing their commuting flow and spatial distribution across multiple occupation groups. The average commute distance in my thesis can be compared with estimates in the New Zealand Household Travel Survey.

Another limitation of this thesis is that individuals' house prices and corresponding house features are not available. IDI census data provide demographic information for individuals, along with income and work data, but housing prices and housing costs are available only in the Household Economic Survey (HES), which represents a small sample of the census population. Such data would have added value to my research by investigating the residential location choices of home-owning multiple-worker households. Moreover, the research time range is limited by the data quality issues affecting the 2018 census and the inconsistent geographic boundaries between the 2013 census and the 2018 census. Estimating a longer-run relationship from 2001 to 2018 between the housing affordability and spatial mismatch of individual key workers is possible only when Statistics New Zealand publishes census data with consistent geographic boundaries.

The third limitation of this thesis is that I did not apply spatial econometrics to test the association between commuting and other variables in the datasets. The spatial econometrics method is applied to capture the location attributes in the estimation. There are several reasons below that I did not apply spatial econometrics measurement. First, some control variables such as the deprivation and school decile have already captured part of the location attributes. Second, it is about the technical limitation of the Statistics NZ Data lab. The spatial econometrics need to construct the coordinate matrix and incorporate the matrix in the empirical models; however, the individual level estimation may involve a large dataset that can not be achieved in the Data lab. Third, the excess commuting under the spatial econometrics method is hard to interpret. The dependent variable in my model is the excess travel distance. If the spatial econometrics method has been applied, a lag of autoregressive excess travel distance will involve. A temporary time change of the excess travel distance may not easily be interpreted, and there is a lack of an economic theory basis for this lag of autoregressive terms.

6.3 Future studies

In this thesis, I have introduced the excess commuting measure to visualise the commuting flow and have explored the relationship between housing affordability and spatial mismatch of key workers, investigating how job location uncertainty and commuting costs influence multiple-worker households' choice of residence. To further explore the ways in which multiple-worker households' choice of residential location is constrained, and to better access the housing needs of workers – particularly key workers in New Zealand – several studies could be conducted of key workers and workers who are home-owners.

First, researchers could visualise excess commuting by renters and homeowners across employment groups. Understanding the spatial distribution and commuting patterns of renters and homeowners could further distinguish the extent of their excess commuting and illustrate the dispersion of job–housing mismatch, respectively, allowing developers and policy-makers to identify the housing needs of renters and owners more accurately while gaining location-based insights into the development of affordable housing.

Second, in relying on census data from IDI in Auckland, the analysis and findings presented in this thesis provide a snapshot of Auckland. A latitudinal analysis using the model developed in this thesis would offer additional insights that could support policy development by capturing cross-region trends. Thus a future study could repeat this study in other regions of New Zealand, such as Wellington and Hamilton, to identify and compare key workers' excess commuting patterns and spatial mismatch among regions.

Third, this thesis applies the median multiple, which is a simple and widely used housing affordability measurement. However, several measurements estimate the extent of housing affordability. In the future, housing affordability could be measured using other metrics, such as residual income. Besides, the empirical analysis can apply quantile regression based on income quantile. Accordingly, spatial mismatch and housing affordability can be analysed at different income levels in terms of income quantiles

6.4 Policy Implications

Amid declines in homeownership, increases in housing costs and concerns about the spatial mismatch between housing opportunities and jobs, this thesis reviews the evidence for how increasing housing costs affect key workers. This section brings together my overall research findings, New Zealand housing policy and potential policy development directions to help key workers access affordable housing.

6.4.1 Transportation sector

Improving transportation policies can alleviate excess commuting among key workers. The spatial distribution of workers' excess commuting flow patterns indicates increasing excess commuting in Northern, Southern and Western Auckland among key workers, who are the most sensitive to the dynamic of housing affordability. Two aspects of the transportation sector could offer ways of easing the stress of excess commuting among key workers.

First, the public transportation infrastructures in Western Auckland and far Northern and Southern Auckland should be developed, in recognition that significant numbers of key workers commute among those areas. As key workers increasingly commute between Northern Auckland and the city centre, extending the train route to Northern Auckland would benefit key workers in those areas. South Auckland is becoming another job centre for key workers, but public transportation is lacking in far Southern Auckland. Eventually, bus service could be developed in far Southern Auckland.

Second, offering key workers transportation subsidies would help them save for the down payment needed to purchase a home. Auckland Transport divides Auckland into nine zones, and the more zones a bus line serves, the higher the fare. No individual bus or train trips exceed five zones, suggesting that transport fares could reach $11.50. Excess commuting is the most severe problem key workers face, with travel by public transportation sometimes spanning several zones. Auckland Transport offers a monthly pass. In recognition of their association with fixed job locations, higher levels of institutional loyalty, and lower turnover rates, key workers could receive a transport subsidy or be allowed to purchase a yearly pass for their specific route.

6.4.2 Housing sector

The increasing cost of housing has concerned New Zealand governments for several decades (Productivity Commission, 2011, 2012; Parliament, 2008; NZ Stat, Mitchell and Malley, 2004), prompting policies aimed at improving housing affordability (Ministry of Housing and Urban Development, 2018). Housing affordability depends largely on household income and house prices. The Overseas Investment Amendment Act was enacted to prevent foreign speculators from bidding up the housing market, with the bright-line test extended from 2 years to 5 years to prevent investors from seeking quick capital gains, thereby preventing the housing market from overheating. Table 11 lists the policies and programs instituted to help New Zealanders access homeownership and to increase the housing supply with a view to reducing housing costs.

The New Zealand Government's National Policy Statement on Urban Development (NPS-UD), made with a view to providing more affordable and accessible housing, relieved some constraints in the planning system and made it easier for people to build and live where they want in the home of their choice. NPS-UD permits taller, denser buildings in the city centre, offering a chance to work and live where productivity is highest.

Other programs target first home buyers. For example, the Kiwibuild programme planned to deliver 100,000 houses for first home buyers, targeting the Government reset to 16,000 houses. Although the Kiwibuild programme seems to alleviate the spatial mismatch problem among key workers, its progress casts doubt on its ability to actually do so.

Key workers are eligible for the programme but need at least a $50,000 down payment to purchase even the most modest Kiwibuild home (Newshub, 2018). The national household saving ratio has decreased since 2012 and is negative from 2015, implying that New Zealanders lack a sense of saving (Reddel, 2018; NZ Stats, 2016). Amid these circumstances, key workers face further barriers to Kiwibuild homeownership, with their median household income an estimated $55,000 (NZ Stats, 2017). Furthermore, even though Housing New Zealand provides up to a $10,000 grant to first-time buyers, applicants must meet certain criteria and are limited by certain rules. For example, the grant value is according to year join in the workforce, a granted employee can get only a $1,000 grant, and buyers' parents are treated as joint purchasers if they help with a downpayment so that annual income of up to four purchasers must still be below $130,000. The application also takes time to process.

Table 11 Policy and program of affordable housing

Year	Name	Eligibility	Summary	Target	Updates
2016 2020	National Policy Statement on Urban Development (NPS-UD)		This national policy statement covers development capacity for both housing and business to recognise that mobility and connectivity between both are important to achieving well-functioning urban environments. Planning should promote accessibility and connectivity between housing and businesses		
2018	KiwiBuild	1. First home buyers 2. Income less than $120,000 (sole buyers) and $180,000(more than one buyer) 3.Contribute to KiwiSaver at least 3 years	New Zealand Government aims to build 100,000 affordable homes for eligible first home buyers. And they reset the target to 16,000 homes	Deliver 100,000 houses in 10 years	452 houses have been completed at the end of June 2020
2019	Affordable Housing Fund			The affordable housing fund to support developers of affordable rental homes at sub-market rates and homes sold under progressive homeownership	
	Social Housing	1. Income under $655.41 a week if single without children, income under $1008.33 a week if have a partner or children 2.Have serious housing needs, difficult to find a private rental meets the needs	New Zealand Government with other 40 organisations provide subsidised rental housing through state-owned housing managed by Housing New Zealand	The 63,000 state houses managed by Housing New Zealand provide homes for over 184,000 people, including tenants and their families. There are 14,869 people on the waiting list at the end of December 2019	2726 state housing and 470 community houses finished at the end of March 2020
	First Home Grant	1. First Home buyers 2. Income less than $95,000 (sole buyers) and $150,000(more than one buyers) 3. Contribute to KiwiSaver for 3-5 years	1. If you buy a new home or land to build on, you can get $2,000 for each of the 3 (or more) years you paid into the scheme. The most you can get is $10,000 for 5 or more years 2. If you buy an existing home, you can get $1,000 for each of the 3 (or more) years you paid into the scheme. The most you can get is $5,000 for 5 or more years.	Up to $10,000 Grant	
	First Home Loan	1. First Home buyers 2. Income less than $95,000 (sole buyers) and $150,000 (multiple buyer) 3. 5% of purchase prices of the house deposit 4. Prices must be less than the regional house price cap	First Home Loans are offered by selected banks, building societies and credit unions and designed for first home buyers who can afford to make regular repayments on a home loan but have trouble saving for a larger deposit.	Depends on the price of the house purchase	Failing to help the first-home buyers in Auckland and Wellington
2020	Progressive Home Ownership (PHO) Fund	1. Households earning up to $130,000 2. Lower to median income families that are unlikely to buy a home without financial support 3. Above median income families cannot get a large enough deposit 4. Auckland and Queenstown Only 5.Māori, Pacific peoples, and families with children are the priority groups.	The PHO Fund will support these households by enabling more people to enter into ownership through shared ownership, rent to buy and leasehold schemes.	Progressive home ownership schemes are one way that can enable a lower deposit or income for households as a result of Covid-19 to still buy a home. A specific focus on Māori and Pacific families with children will be assisted through the PHO Fund.	PHO is already helping 166 families into homeownership

The findings discussed in my thesis offer a clear policy rationale for helping key workers access housing near their workplace and suggest that failure to do so could threaten public health, safety and overall liveability. However, the housing needs of key workers are not noted in the planning and housing strategies of the New Zealand Government, and the policies described herein do not target key workers as such. Specific policy approaches to, and strategies for addressing the housing needs of key workers could include using public sector land to deliver affordable housing for key workers, encouraging employers to develop homes for key workers and developing a government shared ownership program for properties.

Government support for developing purpose-built and professionally managed rental housing in New Zealand could facilitate access to housing for key workers, especially in places with low vacancy rates. Scaling up the rental housing sector would be a more profitable proposition if landlords were required to lease a proportion of units to key workers, prioritise key workers when renting units, or include affordable rental homes in their developments for use by low- and moderate-income key workers. Governments could also help key workers access adequate information about affordable housing options (market rate and affordable housing) near major key employers and expensive housing markets, such as through centralised property listing and enquiry services.

6.4.3 Land use planning

Land use planning policies can be considered as the third approach to improving housing affordability and enabling a well-functioning urban environment. Regardless of occupation, excess commuting patterns show the concentration of workers' residences in southern and central Auckland. A National Policy Statement on Urban Development (NPS-UD) has been published by the New Zealand government with the goal of integrating more people, community services, and businesses into urban areas. NPS-UD requires providing greater height and density plans in city centre zones. In the case of Auckland, the council could prioritize building properties that are higher in height and density in the southern and central areas of Auckland as the priority.

Second, it is crucial to develop the amenities that both offer job opportunities for key workers and improve the infrastructure of communities in western Auckland since there is an increasing trend of key workers moving to western Auckland. Considering key workers are those workers who provide essential services and function the urban economy and development, it is imperative to enhance the accessibility of key worker workplaces nearby their residences and enable them to provide timely services. And nurses and community services workers are the primary part of key workers. Auckland Council could propose a zoning plan to build a new job centre for key workers, such as a new public hospital in western Auckland.

Third, easing the land use type restriction would improve community amenities and urban growth. Key workers suffer the longest excess commuting due to either being unable to find a job near the workplaces or having difficulty affording houses close to the workplaces. It might be possible for the government to allow more mix-use development plans in some affordable areas, which would encourage general practitioners to hold clinics and bring in more job opportunities for key workers in farther southern and northern areas. On the one hand, relaxing the land use type limitation can help decentralise key workers' job opportunities; on the other hand, this policy is also in line with the Auckland council’s long-term strategic planning for accommodating urban growth.

Appendices

Appendix 1: Definition of Key workers

There is no single definition of what constitutes a "key worker", and the definition is always context- and location-specific. The term usually refers to employees in services that are essential to a city's functioning. Often, key workers can be defined as the cohort of low- to moderate- income earners who work in the public sector and provide services essential to cities' functioning and livability. This definition includes low- to moderate- income public sector workers like teachers, healthcare and emergency service workers and other workers such as cleaners and delivery drivers. In this thesis, I also define key workers in their specific context and along with the objective of the corresponding study. This thesis performs two-dimension analysis; one is the aggregate-level analysis (Chapter 4), another is the individual-level analysis (Chapter 2 and 5). In chapters 2 and 5, I utilise workers of seven occupations under two categorises as the proxy of key workers. The data is sourced from the Integrated Data Infrastructure (IDI) when conducting individual-level analysis, which provides the occupations at the six-digit level and detailed workplace meshblock. Therefore, I can identify the specific occupation and job location of individuals through IDI data. In chapter 4, I utilise three primary occupations under two categories as the proxy of key workers for the following reasons. First, there is approximately 70%[15] key workers population is made up of education, health, and community service workers. Second, both seven occupations and three occupations are sourced

[15] Table 1 has shown that school teachers, nursing, and health workers take approximately 70% proportion of key workers in 2013.

from two categories (The starting digit is “2” and “4”). Third, some of the general job locations of key workers cannot be identified at the aggregate level. Thus, chapter 4 utilises only the education, health and communities service workers as the proxy of key workers.

Appendix 2: The mathematical proof on four possible scenarios in the two-worker, two-period, two-centre (2W×2P×2C) model

The proof process of four possible scenarios:

(1) they both remain at the current job location

Under this situation, we assume that $\beta_1 \approx 0$, $\beta_2 \approx 0$, indicating that they both remain at the current job location

$$\tau_H = m\left[e^{w(z-a)} + e^{wa}\right] + \delta n\left[e^{w(z-a)} + e^{wa}\right] \quad (24)$$

To minimise the commuting expenses, the conditions is:

$$\frac{\partial \tau_H}{\partial a} = mw\left[e^{wa} - e^{w(z-a)}\right] + \delta nw\left[e^{wa} - e^{w(z-a)}\right] = 0 \quad (25)$$

$$e^{w(z-a)} = \frac{2(mw + \delta nw)}{2(mw + \delta nw)} e^{wa}$$

$$a = \frac{z}{2} \quad (26)$$

As stated in Equation (26), when two workers in the household are all certain with their job location and no intention to change the job, the residents in the middle of two job centres will minimise commuting expenses and maximise the utility.

(2) the worker who works at C_1switches to C_2 whereas the worker at C_2 remains at the same job location

Under this situation, we assume that $\beta_1 \approx 1, \beta_2 \approx 0$, indicating that they both remain at the current job location

$$\tau_H = m\left[e^{w(z-a)} + e^{wa}\right] + \delta n\left[e^{w(z-a)} + e^{w(z-a)}\right] \tag{27}$$

To minimise the commuting expenses, the conditions is:

$$\frac{\partial \tau_H}{\partial a} = mw\left[e^{wa} - e^{w(z-a)}\right] + 2nw\delta e^{w(z-a)} = 0 \tag{28}$$

$$e^{w(z-a)} = \frac{m}{m - 2\delta n} e^{wa}$$

$$a > \frac{z}{2} \tag{29}$$

As stated in Equation (29), when one worker change the job location from C_1 to C_2 and the other workers remain at C_2, indicating that the worker works at C_2 have more certain with his/her job location; the household is more willing to reside closer to their workplaces, rather than the city centres.

(3) the worker who works at C_1 remains at the same location while the worker who works at C_2 moves to C_1

This situation has been proved in the hypothesis development.

(4) the worker at C_1 changes to C_2 and the worker at C_2 switches to C_1

Under this situation, we assume that $\beta_1 \approx 1, \beta_2 \approx 1$, indicating that they both will change the job and more uncertain with their job location

$$\tau_H = m\left[e^{w(z-a)} + e^{wa}\right] + \delta n\left[e^{w(z-a)} + e^{wa}\right] \quad (30)$$

To minimise the commuting expenses, the conditions are:

$$\frac{\partial \tau_H}{\partial a} = mw\left[e^{wa} - e^{w(z-a)}\right] + \delta nw\left[e^{wa} - e^{w(z-a)}\right] = 0 \quad (31)$$

$$e^{w(z-a)} = \frac{2(mw + \delta nw)}{2(mw + \delta nw)} e^{wa}$$

$$a = \frac{z}{2} \quad (32)$$

As stated in Equation (32), when two workers in households are all uncertain with their job location and will change the job, they reside at the middle of two job centres to minimise commuting expenses and maximum household utility.

Appendix 3 The proof process of different commuting costs situation

The condition of minimum commuting cost becomes:

$$\tau_H = m\left[e^{w_2(z-a)} + e^{w_1 a}\right] \tag{33}$$

$$\frac{\partial \tau_H}{\partial a} = m\left[w_1 e^{w_1 a} - w_2 e^{w_2(z-a)}\right] = 0 \tag{34}$$

There are two possible situations: 1) $w_2 \gg w_1$, 2) $w_2 \ll w_1$ by considering different commuting costs. Considering the situation that when $w_2 \ll w_1$,

$$\begin{gathered} e^{w_2(z-a)} = \frac{w_1}{w_2} e^{w_1 a} > e^{w_1 a} \\ a < \frac{w_2 z}{w_1 + w_2} < \frac{1}{2} z \end{gathered} \tag{35}$$

It indicates that when a worker in a two-worker household has a higher rate of increase in transportation cost, say $w_1 \gg w_2$, would be more willing to pay a rental premium to live closer to the job location of the worker who has higher commuting costs.

Appendix 4 The description of matching process of meshblock data in IDI

The meshblock is the samllest geographic unit for which statistical data is collected and processed by Stats NZ, and it is defined by a geopgraphic area, which can vary in size from part of a city block to a large area of rural land (Stata NZ, 2017). The meshblock pattern is updated each year, it comprised 46,637 meshblocks in 2013, increasing to 53,589 in 2018 (Stats NZ, 2018). Therefore, there is a possibility that the meshblocks code and the centroid of the meshblocks will change across the years.

This thesis covers two census years including year 2013 and year 2018. To make the distance between meshblocks can be calculated at the same standard, I paired the residence meshblock and workplace meshblock for different census years separately. The meshblock information in Datalab shows the information which is the corresponding meshblocks in 2013 and in 2018. Figure 3 shows the data matching process in IDI Datalab. The purpose of this step is to convert the meshblock in corresponding census year to same comparison year and calculate the distance.

For census data in 2013, the census data provides the residence meshblock and workplace meshblock in 2013 while the geopgrahy data in Datalab provides the meshblock codes in each year. Since these two datasets do not contains the coordinates information to calculate the distance. Therefore, the concordance data is required to obtain the coordinates of meshblock centroid. This step is the special step only for census year 2013 due to the data structure of 2013 census data in IDI. After the corresponding coordinates of centroid of meshblocks are obtained, I calculated the distance by using the coordinates.

For census data in 2018, I can figure out the residential meshblock and workplace meshblock in 2018 in census data, and the meshblock metadata provides the match codes for 2018 data and 2020 data and the coordinates. I can use these two datasets to match the meshblocks and calculate the distances.

Appendix 5 The turnover rate of workers from 2001 to 2018

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Average	17.3	16.7	15.9	16	16.5	15.8	16.5	15.2	13	14.8	14.7	13.7	14	14.3	14.3	14.6	14.6	15.3
Agriculture, forestry, and fishing	35.7	35.1	33.4	33.2	33.6	32.9	33.6	33.4	30.7	30.8	31.7	30.7	30.5	30.9	30.3	30.1	30.2	29.5
Mining, electricity, gas, water, and waste services; and construction	15.5	15.2	14	14.7	14.5	13.9	16	13.6	11.3	12.6	13	12.7	13.1	13.3	12.9	13.9	13.5	13.4
Manufacturing	14.5	13.7	12.9	13	12.6	12.8	13.6	12.4	10.9	11.8	11.8	11	11.3	11.3	11	11.7	11.8	11.6
Wholesale trade	13.6	13.4	12.8	12.6	13.5	12	12.9	11.4	9.4	12.7	10.4	9.8	10.9	10.8	10.7	10.7	11	11.6
Retail trade	19.9	15.6	15.6	16.2	16.6	15.8	16.7	14.7	11.5	15	14.4	12.9	13.4	14.3	14	14.1	13.6	14.7
Accommodation and food services	25.8	24.5	25.1	25	25.4	24.6	25.9	24.8	21	23.1	23.4	22.4	22	22.8	22.7	24.1	24.1	24.7
Transport, storage, information media, and telecommunications	15	14.1	13.8	14	13.9	13.2	13.9	13	10	12.3	11.7	10.8	12.1	13.2	12.9	12.7	11.8	13.3
Financial, insurance, rental, hiring, and real estate services	15.7	15.2	13.6	16.1	13.9	14.3	14	12.1	9.6	12.3	12.9	10.6	11.4	12.1	14.7	12	12.6	14.5
Professional, scientific, technical services, administrative, and support services	20.6	20.1	19.8	20.2	21.1	20.4	21.3	19.7	16.4	18.7	18.5	17.7	18	17.8	18.2	18.6	18.9	19.8
Government, arts, and recreation, and other services	13.8	15.4	12.9	13	14.3	13.1	13.8	12.2	11.8	13.7	13.5	12.4	12	12	11.6	12.2	12	13.6
Education and training	12	14.4	13.2	11.8	13.1	12.7	11.9	11.4	11.7	11.1	12.3	10.8	9.8	9.7	10.1	10.5	10.7	11.1
Health care and social assistance	14.1	13	12.1	12.3	13.9	12.3	12	11.6	9.5	11.1	10.6	9.8	10.5	11	10.4	10.9	11.1	11.5
Not elsewhere included	20.7	21.1	16.2	15.9	16.7	14.4	13.6	18.7	16.3	18.2	20.6	20.7	25.4	26.7	23.5	23.9	22.6	20
Rank of turnover rate (descending order)																		
Education and training	1	4	5	1	2	3	1	1	5	1	4	3	1	1	1	1	1	1
Health care and social assistance	2	1	1	2	4	2	2	3	2	1	1	1	2	2	2	2	3	2

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