Rail Location Neighbourhoods:
Proximity Premiums and Residential Sorting

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Abstract

The objective of this study is to determine if property premiums and other rail induced consequences influence demographic characteristics within approximately two kilometres radius of a rail station. The analysis uses two approaches to examine this relationship. First, the study identifies and examines the range of factors that influence the perceived value of rail transit nodes as reflected in nearby residential property values. Second, the study analyses the effect of rail accessibility on the pattern of household incomes and other demographic characteristics nearby rail stations. The analytical methods involve property valuation and assessment of spatial effects on demographic composition. The former employs both global (Hedonic Price Model) and local analysis (Geographically Weighted Regression) to explore the relationships within the multivariate data set. The latter involves ordinary least squares (OLS) regression techniques to estimate the equations.

This dissertation is significant as it is the first attempt to analyse all key demographic variables in a comprehensive exploration of Rail Transit Served Communities (RTSCs). Previous studies in this area have provided only limited explanations of residential sorting, focusing predominately on gentrification in response to recent public rail infrastructure investment. Moreover, this study advances location choice modelling by introducing new rigour and innovation to the analytical process. The empirical results will provide useful and practical quantitative information for policymakers, urban planners, equity advocates and businesses that rely on an understanding of rail induced proximity premiums and residential sorting.

Declaration

Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Advice was obtained from representatives of the Macquarie University Ethics Committee that there was no requirement for Ethics Committee approval for this thesis.

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List of Abbreviations

ABS	Australian Bureau of Statistics
AIC	Akaike Information Criterion
ARP	Attached residential property
BOCSAR	Bureau of Crime Statistics and Research
GEC	Global Economic Corridor
GFC	Global Financial Crisis
GIS	Geographical Information System
GPS	Global Positioning System
GWR	Geographically Weighted Regression
HPM	Hedonic Price Model
NAPLAN	National Assessment Program – Literacy and Numeracy
NSW	New South Wales
OLS	Ordinary Least Squares
RTOC	Rail Transit Orientated Community
RTSC	Rail Transit Served Community
SA1	Statistical Area Level 1 (ABS)
SILO	Simple Integrated Land-Use Orchestrator
TOD	Transit Orientated Development
TRN	Transit-Rich Neighbourhoods

1 Introduction

1.1 Key research problem

A fundamental tenet of urban planning is that transportation networks play a major role in the spatial configuration of cities. In regard to heavy rail, the expansion of networks is viewed as a vehicle to promote employment opportunities, improve urban productivity and encourage population density in order to obviate urban sprawl (Infrastructure NSW 2014). A significant new metro rail project is underway in Sydney aimed at achieving these specific goals. Described as the new 'spine' of Sydney's rail system, the $20 billion two-stage project is Australia's largest ever transit infrastructure undertaking, and the first major effort to invigorate Sydney's rail system in more than one hundred years. Aligned with recent enhanced zoning policy to support polycentricism the project is designed to facilitate expansion of the CBD by decentralising economic activity to Rail Transit Served Communities (RTSCs) within the city's Global Economic Corridor (GEC). Moreover, these policies are expected to underpin the creation of 213,000 additional jobs in the GEC within the next 15 years (NSW Department of Planning and Infrastructure 2013). However, while meeting these objectives is seen as crucial for sustainable long-term urban growth in Sydney there appears to be little understanding of policy impact on residential sorting ('the distribution of households and individuals across neighbourhoods' (Maré et al. 2012)) or little guidance on how to deal with the type of neighbourhood changes that potentially flow from such investment.

> At a time when so many…regions are considering how best to accommodate future growth via public investment, developing a better understanding of its relationship with neighborhood change is critical to crafting more effective public policy. (Zuk et al. 2015, p. 3)

In recent years there has been growing public interest concerning the effects of new public investment programs, such as rail projects, and how they change the prospects of communities and potentially their characters. A multitude of stakeholder community forums have emerged to disseminate information and provide a platform for residents to voice their opinions with respect to new local developments. Many critics raise concerns that potential property value uplift leads to displacement of poorer incumbent residents due to higher rents or land ownership costs, rather than improved social mobility. However, proponents argue that improvements, such as those to transport systems, allow markets to expand, promote specialization and improve labour productivity and productive output. Regardless of approach, both sides of the philosophical debate agree there are a number of implications for the changing nature of impacted communities both in terms of their physical and social character. First, in-movers derive utility from new amenities, and are likely to possess a greater capacity and willingness to pay for closer proximity to the local attributes than those displaced. Second, shifting purchasing power and changing consumer and cultural preferences are expected to alter the mix of retail commercial activity. Third, changing household characteristics are likely to prompt demand for different residential housing types and configurations. Fourth, changes to neighbourhood demographic profiles are expected to alter the type and extent of public amenities and services needed to support these communities. Finally, the ongoing cumulative effects of commercial activity at rail sites may increase the property price trajectory and encourage further change to neighbourhood characteristics. Although there is substantial community debate regarding the issues raised above it is a relatively new area of academic interest. Therefore, very little empirical work has been undertaken to test these suppositions. Regarding public investment in rail, Diaz (1999) states the problem succinctly, as follows:

> Introducing rail transit into a region often creates expectations about the impact of the rail project on property values. Information on the impact of rail on property values is often incomplete and limited to anecdotal evidence, leaving regions planning for rail investments without a firm basis to judge the future impact of such an investment. In addition, this lack of complete information limits the extent to which transit agencies can develop strategies to maximize positive property value impacts. (Diaz 1999, p. 1)

The NSW government's commitment to record levels of current and future funding for significant rail projects highlights the importance of understanding property revaluation and the prospect of residential sorting in response to public transit investment. Given the unprecedented investment in this area, the public can expect to be informed of the implications for communities affected by these decisions from three important perspectives. First, the public must have confidence the government is able to achieve its stated objectives in increasing the economic benefits for impacted communities. Second, it must be assured the government is cognizant of the extent and degree of risk posed to those adversely affected by these projects, and there is adequate provision for these groups. Finally, the public must be aware of the potential outcomes with respect to neighbourhood demographic, social and cultural changes so that planners are better prepared to anticipate community future needs and reduce the prospect of unplanned future outlays.

The paucity of empirical evidence concerning the influence and impact of rail stations on surrounding neighbourhoods represents a major gap in the literature. The current academic discourse relating to this topic centres on the problems and challenges facing researchers, which are primarily underpinned by three interrelated issues. First, scholars are divided on methodological procedures that best define the relationship between property value uplift and changes in neighbourhood profiles. Second, the magnitude of observed property value uplift over space is typically seen as context reliant, which means a generalizable position is problematic.

Finally, there is a lack of reliable long-term data that can be used to develop a theoretical position regarding rail induced property premiums and demographic structure. Current research tends to concentrate on the immediate impact of new rail investment and ignores the effect of long-term residential sorting. The absence of evidence concerning proximity premiums at established RTSC inhibits postulating a contemporarily relevant relationship between rail investment and the structure of neighbourhood profiles.

The challenge presented here is to develop a robust framework in order to understand a broad range of neighbourhood characteristics, at mature RTSCs, including income, education, occupation, unemployment, age, origin, family size, type of tenure and motor vehicle ownership. This framework provides the foundation upon which to establish a process that predicts long-term changes to ‘treated’ (i.e. with rail access) locations. It does this by estimating the contemporary value attributed to the utility associated with rail access and explaining the relationship this has with residential sorting. Specifically, this process involves calculating the differences in both property values and demographic patterns in areas of high and low rail access while considering the local circumstances that catalyse these changes.

This dissertation aims to provide the first comprehensive analysis of rail infrastructure impact on residential sorting nearby rail access points. In particular, it seeks to reveal neighbourhood demographic profiles likely to emerge at established stations following the sorting process and to explain the circumstances that have a bearing on these outcomes. It also identifies the local benefits and disbenefits that may be expected to emerge from new rail investment allowing local authorities to realise the locality’s economic potential and mitigate risks. The information provided by this research can assist community groups and planners to collaboratively prepare for transformation and help enable businesses to take advantage of new opportunities. Overall, the significance of this research will be to reduce the uncertainties concerning the long-term impact of public investment in rail infrastructure projects and allow for more informed strategic decision-making for all stakeholders.

1.2 The impact of the study from different perspectives

The present research will expand our understanding of the benefits and disbenefits due to the changing nature of communities surrounding rail transit access points by identifying the economic, social and behavioural aspects of neighbourhood change that emerge in response to the presence of rail infrastructure. The findings of this study will assist in understanding the importance of these aspects to better inform decision-makers particularly regarding new rail transit investments. In this section, the impact of the study is explored from government, community, business and academic perspectives.

1.2.1 Government perspective

Major investment in physical infrastructure, until recently at least, has largely disappeared from Australian State Governments' agendas. It has been argued that a lack of investment in infrastructure significantly reduced Australia's competitiveness and was a major contributor to the reduction in Australia's productivity growth between the years 1994/2004 and 2004/2011 (D'Arcy & Gustafsson 2012; White 2012). Conversely, a study by Berger (2013) shows, in the wake of the Global Financial Crisis (GFC), that governments around the world have actively pursued the benefits of stimulus provided by urban rail infrastructure to facilitate future growth. In response to the success of these programs, the New South Wales government announced in 2010 an $8.2 billion, 36-kilometre metro rail link between Epping and Rouse Hill in the city's northwest district, and ultimately connecting to Chatswood in the city's north. With construction currently well underway, the government further advised its intention to extend the northwest metro from Chatswood to the CBD via a new harbour tunnel, on to Sydenham in the south and then Bankstown in the city's southwest. This will add an additional $11.8 billion to the overall cost of the project.

The objective of new rail investment in Sydney is to expand the economic capacity of the CBD by facilitating growth within the city's existing GEC. As explained earlier, rail improvements facilitate polycentricism, which increases the effective market size and provides greater economies of scale for commercial businesses and other organizations. They also facilitate specialization at local or connected locations by enabling firms to share in a larger pool of productive inputs, including labour, knowledge and other resources. The economic principle in support of this strategy involves creating economies through the agglomeration principle. Maré and Graham (2009) explain that:

> Agglomeration economies are positive externalities derived from the spatial concentration of economic activity...Since transport investments can increase the scale and efficiency of spatial economic interactions by lowering travel times and improving connectivity, we might expect positive external effects via agglomeration economies. (Maré & Graham 2009, p. 2)

In particular, improvements in the transport network can lead to increases in local productivity through increased 'effective' employment density, which according to Hensher et al. (2012) is defined not only in terms of physical employment numbers but also by their accessibility to major employment locations. 'Improvements in a transport system, therefore, can impact on the "effective" employment density even before or without any of the physical employment numbers changing' (Hensher et al. 2012, p. 1).

At the local level, RTSCs in Sydney provide the major focus for labour concentration and economic activity outside the CBD. These locations offer access to employment opportunities and other amenities that are either nearby rail hubs or connected through the rail network. The cost and time saving advantages of rail at RTSCs potentially attract residents and creates demand for residential sites. The value of local rail transit is then capitalized as a proportion of the total cost of residential space at RTSCs. Stage 1 of the present research aims to isolate this property premium from other factors that enhance the property values of local communities, such as their spatial relationship with the CBD, the designation of locations in terms of their economic status and the availability of alternative transport modes. This premium represents the additional capital value generated by rail transit investment and reflects government success in delivering economic benefits to urban sub-centres in the city's polycentric network.

Policy officials are also concerned with the on-going performance of rail infrastructure in satisfying community needs. To maximize the value of rail investment, governments must ensure access to services for those who are likely to benefit most from rail transit. Hence, there is a symbiotic relationship between certain demographic groups and successful transit (Pollack, Bluestone & Billingham 2010). The present study considers a number of aspects concerning the effectiveness of rail transit as a public service. Initially, there is an investigation to ascertain if rail induced property premiums are, in fact, associated with rail transit uptake. It is not in the interests of government or the public if residents nearby rail stations have the capacity to pay for local property premiums but do not utilize the rail transit system and, instead, rely heavily on motor vehicle transport. Following this exercise, the study broadens investigation of RTSC demographic profiles to reveal which groups are prominent at these locations, their propensity for rail travel and the pattern of motor vehicle ownership.

1.2.2 Community perspectives

Community based groups, including those involved in advocacy and local governance, have a strong interest in understanding the impact of new rail infrastructure on local demographic patterns. Advocacy groups typically arise in response to local and sometimes broad community issues associated with trends in people movements, policy decisions and private or public capital inflow. Local issues concern events that are likely to alter existing community values or culture. Broader issue advocacy groups pursue matters such as resident displacement, greenfield acquisition, residential densification, auto-dependency and sustainable transport systems. Regarding the aforementioned group, local governance often involves elected community leaders whose task is to guide community change and oversee the introduction and implementation of appropriate social infrastructure to meet anticipated community needs. Understanding each element of demographic composition enables local administrators to make more informed decisions concerning future social infrastructure requirements at new RTSCs.

The study also addresses a number of rail related contemporary social policy issues that concern advocacy groups from the broader perspective. These include rail induced displacement, the propensity for public uptake of rail transit and the spatial relationship between rail transit and motor vehicle ownership. Estimates of rail induced property value uplift also provide a guide to the value capture potential of rail investments. Value capture is a technique aimed at realizing revenue from increased land value in the catchment area of public infrastructure investments. This revenue can provide a means to fund neighbourhood betterment schemes and help mitigate displacement caused by localized, upward property revaluations. In general, improved understanding of both the effects and underlying mechanisms associated with neighbourhood re-composition enable the development of policy tools that may be used to shape equitable neighbourhood change in both old and new RTSC developments.

1.2.3 Business perspectives

The prospect that populations sort into communities where residents display common interests and values has significance for the way business views the opportunities associated with rail transit locations. For example, it is likely that home-seekers are inclined to accept property premiums for nearby access to rail transit if the location provides sufficient utility to justify the additional cost. If this is so, it would seem reasonable to hypothesize that some form of geographic concentration, based on similarity of preferences for the utility offered by this amenity, may arise that differentiates RTSCs from other non-rail urban locations. How this translates to the concentration of demographic characteristics associated with life cycle and life-style is a major issue addressed in this study. This type of evidence relating to geographic segmentation is important for businesses to anticipate market needs and wants, to develop effective strategic plans and to allocate resources more efficiently.

The research will also assist residential property developers to improve their understanding of RTSC housing markets and enable them to make more informed decisions in three important ways. First, this research will allow developers to accurately assess the potential profitability of prospective sites by estimating consumers’ willingness to pay for rail accessibility and proximity to amenities that surround rail stations. Second, it will assist planning decisions, at RTSCs, concerning design selection by estimating the demand elasticity for various housing features in the context of neighbourhood demographic structures. This leads to more accurate cost benefit analysis of alternative structural configurations enabling developers to optimize product offerings. Finally, the research will provide a useful methodological approach to help deliver greater certainty for developers seeking suitable land acquisition at rail sites for future improvements by revealing likely changes to population characteristics over time and the affect this has on housing demand.

1.2.4 Academic perspectives

Land value theory has long been of interest to academia, however, there remains considerable knowledge gaps in this area of study. Land value theory has its foundations in the work of early nineteenth century political economist David Ricardo (1817) who postulated the ‘law of rent’, which argues that land rent is equivalent to the economic advantage obtained from a land parcel used in its most productive capacity. Early empirical analysis to test this thesis began with Rosen’s (1974) model, which imputes values of property features by estimating the relationship between property price and quantities of the property’s attributes. The model posits that land utility is derived from a mix of differentiated factors such as housing structural features, proximity to public amenities and neighbourhood attributes. Public or private investment in neighbourhoods is believed to influence these factors, alter the land value/utility equilibrium and in doing so change spatial demographics.

An alternative approach, which tends to dominate empirical studies in this field, is to explain neighbourhood transformation in terms of flows of people rather than capital (Zuk et al. 2015). This theory has two branches, both grounded in consumer-driven, demand-side principles. The first branch deals with home-seeker preferences and their desire for particular urban experience, or those that seek the authentic or unique character of a location (Brown-Saracino 2010; Caulfield 1994; Ley 1996; Zuk et al. 2015; Zukin 1989). The second branch is largely a product of neoclassical economics linking property values to home-seeker locational choice, which follows shifts in the labour market (Hamnett 2003).

Contemporary debate concerning neighbourhood transformation has generally been divided along the lines of capital or people flow. Zuk et al. (2015) point out this dichotomous narrative means analyses are commonly focused on either supply-side production or demand-side consumption catalysts. Studies concerning the flow of capital focus on profit seeking and the effect of broader economic forces, which make locations attractive to in-movers. Conversely, studies concerning the flow of people refer to individuals' attraction to locations based on their particular preferences. The problem with separating these analytical approaches is that it narrows the focus of studies and limits their ability to address the broader issues. In the context of transit investment, the present study employs both branches of mobility theory (the likelihood of intraurban migration) to explain the nexus between catalysts, neighbourhood transformation and land value.

Another limitation of the current literature is that it mainly focuses on the process of gentrification dealing predominately with the decline and subsequent revitalization of neighbourhoods. The central theme of these studies is generally limited to the differential impact on incumbent and new neighbourhood residents in terms of the burden and benefits of change. In these studies, the broader role of public investment, and in particular the role of rail investment, is typically absent from the investigative process. Moreover, gentrification studies are largely confined to analysis of just two aspects of demographic profile that are used to gauge the effects of change, namely race and class. The present research attempts to introduce a broader scope of study and enhance applicability to a wider audience of researchers who seek to better understand the contemporary issues of neighbourhood transition, particularly concerning the implications of public investment. Finally, by revealing the extent to which changes in neighbourhood characteristics support the objectives of government this research aims to make a significant academic contribution in an area of major importance to Australia's economic future.

1.3 Conclusion

There is growing interest in the potential to increase productivity of cities by decentralizing economic activity and introducing urban polycentricism. A decentralized urban economy offers business and other organizations a wider choice of development space and encourages specialization by allowing greater access to labour and markets. Increasingly, administrators are turning to new and existing rail infrastructure to provide the basis for efficient spatial connectivity, which is fundamental to the success of decentralization schemes. Therefore, it is important to understand the effect of rail infrastructure in transitioning local communities into productive centres and how these changes affect the nature of those communities. This study investigates how the characteristics of locations with different roles in the urban economic system are influenced by rail transit accessibility and reveals how changes from rail investment meet the objectives of strategic players.

To address the broad range of issues outlined above, it is necessary to conduct the proposed study in two stages. The first stage examines the attributes and circumstances that influence the magnitude of rail induced property premiums at RTSCs, in Sydney. This involves an empirical investigation to determine the influence of contemporary rail on property prices. The second stage investigates the sorting of residents. In this case, the analytical process examines residents' location choices in response to rail accessibility and other spatial factors likely to influence decisions of residential selection. The estimates from both stages of this research help to predict changes to neighbourhood characteristics at locations earmarked for future rail stations. The information provided by this study will lead to a more efficient allocation of resources for government and business, and better inform community groups whose interest is to retain or improve the character of neighbourhoods.

1.4 Research objective and questions

1.4.1 Research objective

The objective of the present study is:

To determine the magnitude of rail induced residential property premiums across the Sydney metropolitan area and to reveal how, and to what extent, rail accessibility predicts the spatial distribution of demographic groups.

This study addresses a number of related questions, which are formulated as the basis for a two-stage study that combine to satisfy the research objective.

1.4.2 Research questions

In order to provide a solution to the research objective it will be necessary to investigate the relationship that rail accessibility has with both property premiums and residential sorting. Establishing the first relationship requires identifying the attributes and contextual factors that influence the size of rail induced proximity premiums. Understanding the second relationship involves examining the population characteristics of high rail-accessible neighbourhoods and comparing these to neighbourhoods with low rail access[1]. The analytical framework can be used as a basis to predict long-term changes in price premiums and the spatial distribution of populations following the process of residential sorting at future RTSCs.

[1] Areas with low rail access are beyond those considered to be walking distance to a rail station. These areas are unlikely to have rail induced property premiums.

The procedures outlined above divides the research task into two stages. Each stage evokes a general question that in turn is addressed by considering a series of sub-questions relating to the particular stage of the study. The general questions and sub-questions applicable to each research component are shown below.

Stage 1

RQ1: Do RTSCs exhibit residential property proximity premiums and to what extent are they rail transit induced?

> *RQ1a: What do the observations reveal about local spatial variability, particularly as it relates to rail induced residential property premiums?*
>
> *RQ1b: What accessibility factors are most influential in determining property values at RTSCs and how do these compare with the effects of other structural and neighbourhood characteristics?*
>
> *RQ1c: How do premiums of property prices differ amongst locations targeted for different strategic economic roles?*

Stage 2

RQ2: Does the demographic profile of residents in high rail access neighbourhoods differ from that in neighbourhoods with low rail access and, if so, is this rail related?

> *RQ2a: Is there a relationship between property price premiums and the demand for rail transit?*
>
> *RQ2b: Does a higher level of rail usage correspond with higher concentrations of specific demographic groups and, if so, which groups demonstrate this relationship?*
>
> *RQ2c: What role might population density and housing type play in determining* residential *sorting at locations nearby rail access sites?*
>
> *RQ2d: What influence does rail access have on local demographic patterns?*

The two main questions posed above support the research objective based on the following rationale. The first question is directed at understanding property values nearby rail access and the contextual circumstances that determine proximity premiums at these locations. The second question seeks to ascertain evidence that identifies the relationship between rail-accessibility and residential sorting. Combining evidence from both aspects of research reveals which resident groups underpin the property premiums associated with rail access and the groups who are otherwise unwilling or unable to pay for such access. The information derived from addressing these questions will help predict changes to property prices and location characteristics at rail sites in equilibrium. This also provides a position from which to assess the benefits and disbenefits associated with rail investment.

1.5 Hypotheses, tasks, approach and scope

The research schedule outlined above involves hypothesis testing. Hypotheses only apply to testable questions. This section specifies the hypotheses and provides a brief account of the tasks, approach and scope for all aspects of the present study.

Stage 1

Hypotheses:

Hypothesis 1a:

In relation to the Sydney metropolitan area, there is no significant difference in average residential property prices due to rail station proximity.

Hypothesis 1b*:*

Larger commercial complexes surrounding rail stations do not lead to higher local property values.

In order to test the hypotheses, there is a need to estimate the influence of rail transit accessibility and other factors on nearby residential property values. This invokes the theoretical prescriptions relating to land value. The literature review in this dissertation explores the development of concentric zone theory and Alonso's (1964) theoretical framework relating to bid/rent. This leads to the Rosen (1974) Hedonic Price Model (HPM), which is used to isolate the value of proximity to transit services and other factors that affect property value.

This research employs a similar approach to that used by Debrezion, Pels and Rietveld's (2011) study analysing the effects of fixed proximity attributes. For the purpose of this study, the HPM is applied to house sale price observations surrounding train stations at impact and control areas to estimate transit induced property proximity premiums and those premiums that result from other attributes that surround those stations. Later, Geographically Weighted Regression (GWR) is used to test the spatial variation of rail induced property price premiums. A selection of heavy rail hub sites, differentiated by the size and economic importance of the location, is considered in this study and analysis focuses on the 2011 census year.

Stage 2

Stage 2 questions *RQ2a* to *RQ2c* are addressed through descriptive analysis. *RQ2d* concerns the primary focus of Stage 2 research and is testable. Each demographic variable is examined in the analytical phase. The full range of variables considered is as follows:

Income

Educational attainment

Occupation

Unemployment

Age

Australian born

Families with dependants

Renters

Motor vehicle ownership.

This research is designed to test the assumption that the benefits and costs of the utility offered by nearby rail access are key determinants of residential sorting. Neighbourhoods with high rail accessibility derive utility from rail transit, which is reflected in the location's property premiums. The utility offered and premiums incurred represent the benefits and costs of nearby rail access. These can be seen as the advantages and disadvantages, or the externalities, associated with close proximity to rail stations, which potentially influence home-seeker location decisions.

Hypotheses 2a to 2i relating to these variables are as follows;

Hypothesis 2a*: The spatial distribution of residents, according to income, is associated with externalities relating to rail access.*

Hypothesis 2b*: The spatial distribution of residents, according to university qualifications, is associated with externalities relating to rail access.*

Hypothesis 2c*: The spatial distribution of residents described as professionals is associated with externalities relating to rail access.*

Hypothesis 2d*: The spatial distribution of residents described as unemployed is associated with externalities relating to rail access.*

Hypothesis 2e*: The spatial distribution of residents, according to average age, is associated with externalities relating to rail access.*

Hypothesis 2f*: The spatial distribution of residents described as Australian born is associated with externalities relating to rail access.*

Hypothesis 2g*: The spatial distribution of residents described as families with dependants is associated with externalities relating to rail access.*

Hypothesis 2h*: The spatial distribution of residents described as renters is associated with externalities relating to rail access.*

Hypothesis 2i*: The spatial distribution of residents, according to average motor vehicle ownership, is associated with externalities relating to rail access.*

Stage 2 research aims to determine if residential sorting is associated with rail accessibility at different types of established rail locations. The analytical approach involves the application of two criteria, which set the preconditions for causality. To test the hypotheses, OLS multivariate regression is used to analyse the significance of the relationship between demographic characteristics and rail-accessibility during the 2011 census year. The study involves different RTSC categories at different metropolitan districts and their respective control areas.

1.6 Thesis format

This research has a conventional thesis structure. The dissertation comprises eight chapters. Following the introduction, the second chapter presents a review of the theoretical and empirical evidence relating to residential property values, followed by a review of literature concerning urban mobility, displacement, segmentation and the effects of public investment on residential sorting. The third chapter deals with the methodological approach and data collection required for the research study. Chapter 4 outlines the features of the broad subject region, policies and spatial organisation of strategic sub-centres and details of the specific locations to be studied. Chapters 5 and 6 present the research findings and discussions relating to Stage 1 and 2, respectively. Chapter 7 provides an overall discussion. This segment draws the research findings together, responds to the research questions, addresses the hypotheses, discusses the research contributions to the literature and identifies future research questions. Finally, Chapter 8 presents the conclusions, discusses the research contributions to the literature and identifies future research questions.

1.7 Definition of terms

Accessibility

The term ‘accessibility’ is widely debated in transport literature. For the purpose of this study, accessibility refers to ‘the ease with which the land use and transportation systems enable individuals to reach activities or destinations’ (Du & Mulley 2012, p. 52).

Attached Residential Properties (ARP)

These properties include all dwellings in blocks of flats, units or apartments; flats attached to houses such as ‘granny flats’, and houses converted into two or more flats; and semi-detached, row or terrace houses, townhouse and villas with their own private grounds and no other dwelling above or below them. In all cases, ARPs are either attached in some structural way to other dwellings or separated by less than half a metre (ABS 2011). ARP include both Strata and Torrens Title. Strata property owners collectively share the cost of upkeep associated with common walls and other common areas such as gardens, roofs, lifts and driveways. Under Torrens Title the purchaser owns both the land and building.

Displacement

Displacement describes a pattern of involuntary out-movement of current residents as a result of changes to local affordability following an event that leads to neighbourhood transition (Pollack, Bluestone & Billingham 2010).

Gentrification

‘Gentrification is a pattern of neighborhood change in which a previously low-income neighborhood experiences reinvestment and revitalization, accompanied by increasing home values and/or rents’ (Pollack, Bluestone & Billingham 2010, p. 2). Various authors point to the manifestation of gentrification as changes to neighbourhood composition in terms of race, class, the number of professionals, university qualified, unemployed, and renters (Atkinson 2000; Kahn 2007).

High Rise Residential Unit Buildings

Residential unit buildings greater than three floors.

Low Rise Residential Unit Buildings

Residential unit buildings up to and including three floors.

Migration

Migration is generally defined as ‘a permanent or semi-permanent change of residence. No restriction is placed upon the distance of the move or upon the voluntary or involuntary nature of the act, and no distinction is made between external and internal migration’ (Lee 1966, p. 47).

Neighbourhood

Sampson (2012) describes neighbourhoods as the physical building blocks of a city in regard to both 'social and political organization'. This concept combines the physical and non-physical attributes of location to produce 'tertiary communities' defined by delineating street block aggregations convenient for local pedestrian access. This means pedestrians can traverse an area without crossing a major thoroughfare. It provides the primary focus of residents' social interaction (Coulton et al. 2001; Grannis 1998; Sampson, Morenoff & Gannon-Rowley 2002).

Neighbourhoods with high rail access

For the purpose of this study the degree of rail access is determined by the proximity of a neighbourhood to a train station. Neighbourhoods considered to have high rail access are those located less than, or including, 2,000 metres from a train station.

Neighbourhoods with low rail access

The degree of rail access is determined by the proximity of a neighbourhood to a train station. Neighbourhoods considered to have low rail access are those located more than 2,000 metres from a train station.

Place

The commercial complex that surrounds rail stations Bertolini and Spit (2005).

Proximity premium

Land value theory holds that properties close to a location attractor (such as rail stations) incur a price premium, which tends to fall with increased distance from the attractor. This price differential is the proximity premium.

Rail Transit Served Community (RTSC)

A Rail Transit Served Community is a general term used to describe an urban precinct that is within the sphere of influence of a particular rail station.

Residential sorting/sorting

For the purpose of this study, the term residential sorting refers to the process of socio-spatial mobility that leads to the distribution of individuals across neighbourhoods, based on their particular demographic characteristics. Therefore, the result of 'sorting' is the concentration of residents belonging to a particular demographic group (Clark & Morrison 2012; Maré et al. 2012).

Segregation

The term segregation is generally used to describe the spatial separation of demographic (especially minority) groups into distinctive residential areas over time. Massey and Denton (1988) suggest that neighbourhood segregation is a global construct with five dimensions of spatial variation. These dimensions describe the *evenness* of minority group distribution; the level of minority group *exposure* to majority group members; the extent of *clustering* where minority areas adjoin one another over space; *centralization* or the degree to which minority groups settled at the urban centre; and *concentration,* which is the relative space occupied by a minority groups.

Statistical Area Level 1 (SA1)

These areas are designed as the smallest unit for release of Australian Bureau of Statistics census data. SA1s generally have a population of 200 to 800 persons.

Strata Residence

A residence under the legal entity ‘strata title’ (generally an apartment, townhouse or villa), whereby an individual owns part of a property called ‘a lot’ and together share ownership of the common property. Maintenance of common property means owners are subject to a strata fee.

Transit Oriented Development (TOD)

Transit Orientated Developments are urban precincts specifically designed to encourage people to use transit and reduce their auto-dependency. Generally, this means concentrating higher density and mixed land use nearby frequent rail transit stops.

2 Literature Review

The objective of this review is to examine related literature concerning the influence of rail transit induced property premiums and demographic profiles at rail-accessible locations. This involves a review of two different bodies of literature. The first is an account of research relating to public investment in rail infrastructure and its impact on land values. The second deals with various matters including the dynamics of household mobility, the processes of residential sorting and the circumstances that lead to displacement. In both cases, the review explores the concepts and empirical evidence that help define the theoretical framework and analytical tools to be employed in the present study, in order to determine the correlation between transit accessibility on neighbourhood property prices and demographic structure.

The first section of the literature review shows most urban studies relating to land use and land value evolve from the foundations of classical economics and the principles of competitive advantage. The key theoretical concepts to emerge from this debate include concentric sorting and bid/rent relating to property valuation. A vast number of studies have investigated the impact of public investment, including transit investment, on land value. However, very few studies have considered the special relationship between rail-transit investment and neighbourhood demographic transition. Only recently has the latter been elevated in importance, from political, policy and planning perspectives, with the emergence of urban public investment programs designed to catalyse urban growth. The second section of the review explores pertinent theoretical and empirical research relating to these developments.

2.1 Land value: theoretical perspectives

Estimating the relationship between property premiums and rail accessibility invokes the principles of land value theory dealing with market behaviour, in relation to space consumption and locational preference. This section begins with an account of transport related land value theory development from its foundations in the observations of concentric rural land use patterns to the emergence of bid/rent theory in the context of the urban environment. Next, the discussion turns to the methodological processes and tools used to estimate the causal relationship between the presence of rail and property premiums. This establishes the methodology for the first stage of the present thesis. The final segment of this review examines the empirical evidence relating to factors that may be influential in this research.

2.1.1 Concentric zone theory and the 'law of rent'

Land value theory owes its foundations to the work of early nineteenth century classical economist David Ricardo. In his book titled *Principles of Political Economy and Taxation*, Ricardo (1817) postulated the 'law of rent', which holds that land rent is equivalent to the economic advantage obtained from a land parcel used in its most productive capacity, relative to an alternative rent-free parcel with the same labour and capital input. Ricardo's theory is the first to clearly identify the relationship between land rent and land quality, and hence the spatial heterogeneity of land use in terms of intensive as opposed to extensive land production.

Ricardo's principles of land value theory were later refined and further developed by German agriculturalist and amateur economist von Thünen (1830) who conceptualised the relationship between land value and output in terms of market distance. Von Thünen argued that, given the assumption of a pure isolated state, over an isotropic plane agricultural land use is determined by the relative cost of rent, which in turn, is influenced by commodity production costs, market price and the cost of transport to the central market. Von Thünen's model of land valuation can be expressed as:

$$R = Y(p - c) - Yfm \tag{2.1}$$

where:

R = land unit rent

Y = land unit yield

p = market price per unit of yield

c = average production cost per unit of yield

m = distance from the market

f = average freight cost per unit of yield/distance.

Given ubiquitous land characteristics, distance to the marketplace emerges as the key determinant in productivity maximization (rent) in von Thünen's model. Von Thünen predicts that agricultural production intensifies closer to the market centre where property costs are higher and transport distances are small. Conversely, extensive land use is more likely to be found in zones farther from the market where property cost is lower and transport distances greater. Ceteris paribus, the model suggests that land use patterns take the shape of perfect concentric circles. These principles form the basis of subsequent land value–market-proximity relationship modelling.

In the early twentieth century, land economist Hurd (1903) extended von Thünen's theory to the urban context in the new urban paradigm, which by now featured extensive transit infrastructure.

Hurd explained that cities generally respond to axial growth along rail or controlled highways, and this acts as a major influence on the pattern of land valuations. He also showed that while land values are predominately controlled by direct proximity to the city centre, they are also influenced by the superimposition of transport infrastructure, which facilitates urban expansion by effectively reducing the remoteness of outlying urban locations. In this way…

> …value by proximity responds to central growth, diminishing in proportion to distance from various [centres], while value from accessibility responds to axial growth, diminishing in proportion to the absence of transportation facilities. (Hurd 1903, p. 146)

Haig (1926) confirms the relationship between property value and location and stresses the dominating influence of the city centre. He suggests the city's influence is due to its myriad activities and its centrality in relation to surrounding suburban locations. Proximity to these activities gives rise to substantial savings in transport costs and reductions in travel time, which are captured in land value. The relationship between transport costs and land value is therefore a reflection of the demand for accessibility to activities provided by the urban centre. Haig describes this relationship as the 'cost of friction'. He suggests a transport network facilitates the dispersion of business activity, and hence employment opportunities. The pattern and extent of dispersion is determined by access sensitivity. That is, businesses highly sensitive to accessibility tend to gravitate towards the city centre, while those that have low sensitivity choose outer locations.

Concentric zone theory remains a dominant aspect of land value theory. The theoretical principle holds that property values are dictated by their proximity to centres with concentrations of public amenities, and this in turn is influenced by the relative size of agglomeration at these centres. In general, as distance to a commercial centre decreases transport costs fall, and land costs rise. Consequently, residential properties located closer to the centre should, ceteris paribus, exhibit higher prices than those farther away because the cost and time expended on travel is less. Since the 1960's, the challenge for theoreticians has been to measure the effect of transport cost savings on property values.

2.1.2 Modelling bid/rent theory

Alonso (1964) was the first to conceptualise land value theory in a practical model. The model builds on Haig's (1926) theory of land value as a function of proximity moderated by the explicit and implicit cost of transport. Alonso's model posits the concept of a utility function based on the relationship between the inherent cost of transport, household space, leisure time, income and the consumption of other desired goods and services. This assumes households have preferences, which can be measured in terms of indifference curves. A bid/rent function is provided which

indicates the price households are willing to pay for rent at locations with different transport costs offering the same level of satisfaction. Alonso's bid/rent function may be formulated as follows:
$U(h, x, T)$ is the household utility function
and household budget is:

$$px + rh = y + w(1 - t - T) \qquad (2.2)$$

where:

h = the amount of housing space used

x = a composite of other goods and services consumed.

T = leisure time

p = price of consumer goods

r = rent for a unit of space

y = non-wage income

w = wage rate

t = commuting time

In Alonso's model, equilibrium is reached when household rent is equivalent to the marginal cost of commuting time and leisure, as well as the price of other goods and services. This suggests a bid/rent gradient, negatively correlated with distance from the CBD. It also accounts for the geographical differences of household space consumption such as the location preference of higher income households whose decisions are influenced by the relative cost of open land space compared with locations closer to the CBD.

Following Alonso, the extensive works of Muth (1969) and Mills (1967) add weight to the view that the appropriate way to determine urban land value variations is to consider the maximisation of household utility constrained by income, less the inherent cost of transport. However, while the contributions of Alonso, Muth and Mills provide a valuable conceptual basis for empirical studies a practical market application of their particular model is constrained by the frequently intractable analytics involved in more complicated non-monocentric urban settings.

A further issue relating to the Alonso/Muth/Mills model is its inability to provide a meaningful measurement of the bid/rent function. While the model is built on practical observable elements and offers a valuable framework, within which to view the problem, as a tool of analysis it has proved onerous to implement. As a result, this challenged empirical researchers to devise a simpler, more efficient tool to estimate the value of transport infrastructure and other public amenities nested in land value. From this emerged the application of regression techniques and, in particular, the HPM.

2.1.3 The concept of capitalized transport savings

The literature posits that public transit facilities lead to nearby property value uplift if they offer a viable alternative to car travel. The rationale behind this theory is a logical extension of the Alonso, Muth and Mills transport savings model outlined above. It assumes that commuters choose rail transit over alternative means of transport if it reduces total travel costs. The amount saved varies according to trip distance and frequency. Because these savings accrue to households they are capitalized into property values. Therefore, owners who sell properties will seek to extract a premium equivalent to transport savings from prospective buyers. From the buyer's perspective, this premium is considered an investment with a return equal to the transport savings attributable to that location. This can be modelled as follows:

$$SAV = (\alpha D_o + P_o) - (\alpha D_a + F_a) \qquad (2.3)$$

where:

SAV = savings

D_o = distance from origin to the CBD

D_a = distance from the origin to station a on the line to the CBD

P_o = cost of parking at the CBD

F_a = fare from station a to the CBD and return

α = access cost per kilometre including vehicle operation and travel time.

Solving for D_o and D_a yields the hyperbola:

$$D_o - D_a = [(SAV/\alpha) + (F_a - P_o)/\alpha] \qquad (2.4)$$

Savings are maximized when D_o - D_a equals the distance from station a to the CBD, or D_{oa} Therefore, maximum savings are derived as follows:

$$SAV_{max} = \alpha D_{oa} + P_o - F_a \qquad (2.5)$$

Daily travel savings are capitalized into property value as follows:

$$VAL = \sum_{t=1}^{t} (N\,\overline{SAV_i}) / (1+r)^1 = N\,\overline{SAV}/r \qquad \text{as } t \to \infty \qquad (2.6)$$

where:

VAL = the property value increment

N = number of trips per year

SAV_i = savings per trip in year i

r = interest rate.

A simpler method to identify transit induced property premiums is by isolation of the attribute contribution to property values. During the latter part of the 1960s researchers began to estimate the relationship between property value and proximity to public amenities using regression techniques to account for the observable and unobservable determinants of house prices. This concept has its theoretical justification in Lancaster’s (1966) seminal work relating to consumer theory and later to model development by Rosen (1974). The product of contributions from these authors is the emergence of the HPM, which has since provided the basis for the vast majority of empirical studies concerning land valuation and the influence of location, particularly in relation to transit induced property premiums.

2.1.4 Hedonic Price Model (HPM)

The HPM holds that goods possess multiple utility-affecting attributes that combine to form objectively measurable bundles of characteristics. Early model development is well documented Ching and Chan (2003). Some important aspects of the authors’ work are considered in this section.

Pioneer authors, Lancaster (1966) and Rosen (1974), aimed to impute the prices of product attributes by observing variations in prices of differentiated products in response to changes in the frequency of the particular attributes associated with these products. Both authors postulate that, in equilibrium, the price of a marketable good is equivalent to the value of its constituent parts. However, there are some fundamental differences in the authors’ propositions. For example, Lancaster’s model presumes that goods form members of groups that comprise preferred attributes and these goods are consumed in combinations, subject to consumer budgetary constraints. In contrast, Rosen assumes goods are unrelated in terms of preferred attributes, which means goods are chosen from a range of alternative brands and consumed discretely. This distinction suggests Lancaster’s approach is appropriate for the analysis of consumer goods, whereas Rosen’s conceptual model is more consistent with the characteristics of durable goods.

Moreover, Lancaster and Rosen differ in relation to the functional characteristics of their models. For example, Lancaster assumes the relationship between the price of a good and its attributes are both constant and linear regardless of the number of attributes. That is, the relationship between prices and attributes changes only when there is a change in the combination of attributes consumed. On the other hand, Rosen postulates that unless consumers are able to arbitrage attributes by disaggregating and repackaging goods, it is more likely a nonlinear relationship between the price of a good and some of its attributes. Nonlinearity of the price function suggests the implicit price of a good is not constant, rather a function of the quantities of the attributes consumed. Rosen, therefore, offers flexibility of functional form in modelling the relationship between the price of goods and their constituent parts (Ching & Chan 2003).

Rosen's (1974) model explains price equilibrium in two distinct stages. The first stage estimates the marginal price of product attributes by regressing these against the product's price. The second stage involves estimation of the consumer's marginal willingness to pay derived from the inverse demand function. Rosen postulates the latter can be estimated by the implicit marginal price function, which is endogenous to the model. On the other hand, supply price is assumed exogenous and fixed or inelastic in the model and therefore not systematically affected by changes in other model variables. Bartik (1987) concurs with this proposition arguing that HPM estimations are not the result of interaction between supply and demand because of the incapability of individual consumers to affect supply. Rather, an HPM is the result of interaction between price and quantities of attributes, which means it is unnecessary to model the supply function.

In reality, HPMs are neither demand or supply curves. The price model is a function of the attributes of a good consumed and reveals only the marginal valuation of the highest bidder. Therefore, the HPM simply reflects the outcome of market equilibrium processes. In this way, the HPM represents a reduced form of the demand and supply equations.

2.1.4.1 HPM definition.

Rosen's HPM imputes the values of property features by estimating the relationship between property price and quantities of a property's various attributes. The model posits that property values emerge from the valuations of a particular mix of differentiated products from which consumers derive utility and these can be specified by a vector of observable variables $x = [x_1, x_2, \ldots, x_n]$. Hence, the HPM provides an estimation of a consumer's willingness to pay for each property attribute, subject to income constraints and moderated by the consumer's preferences. The implicit value of each factor is reflected in its corresponding coefficient, and a particular bundle of factors produce a property value, which is estimated by the model.

The most common method used to estimate the parameters of the HPM is OLS regression analysis. The model estimates the unobservable factor by the regression equation:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_n X_{ni} + e_i \qquad (2.7)$$

where:

Y = dependent variable

β_0 = constant term

X_n = independent variables

β = estimators or coefficients of the independent variables

i = observation

e_i = error term

The variables used in the model are observable, quantifiable factors, or unobservable factors proxied by either dummy variables or other measurable substitutes. The partial derivative of the function with respect to each attribute, ceteris paribus, represents the implicit marginal attribute price, as revealed in the regression coefficient (Rosen 1974). This means property valuation constitutes the sum of implicit attribute prices represented in the model. By controlling for other property attributes, the model calculates the implicit value of proximity by differentiating the price of the property with respect to the variable representing the property's distance from a particular reference point.

Extant literature reveals many past studies that employ the HPM focus on the structural *(S)*, accessibility *(A)* and neighbourhood *(N)* attributes of properties (Ching & Chan 2003). These attributes encompass both quantitative and qualitative characteristics (Goodman 1978; Williams 1991). Hence, property prices *(P)* can be expressed as a function of these three groups as follows:

$$P = f(S, A, N) \qquad (2.8)$$

A review of literature findings concerning the components of each attribute group and their functional relationship with property valuation is addressed in the following section.

2.1.4.2 Determinants of property values

Property values vary spatially due to their physical structure, accessibility and neighbourhood characteristics. Specifications of the HPM, for residential housing, generally include a vector of attribute variables assigned to each group of characteristics. Common variables used in the literature to represent each group and the procedures for measuring these variables are as follows.

Structural attributes

A major component of a property's price can be found in its structural attributes. Generally, homes with more desirable physical attributes are likely to command higher prices than others, given the same location and neighbourhood characteristics (Ball 1973). However, preferred structural attributes are not always identical. For example, the significance of various structural attributes may change over time and vary between countries (Kohlhase (1991). While studies show room numbers are significant in determining property prices and relatively consistent internationally, the value of other physical attributes may change with traditional building style or climate (Garrod & Willis 1992).

Various studies show that the floor area is positively related to the residential property value (Carroll, Clauretie & Jensen 1996; Rodriguez & Sirmans 1994). This indicates home-seekers are willing to pay more for space, particularly functional space. Hence, the number of bedrooms and their size (Fletcher, Gallimore & Mangan 2000; Li & Brown 1980), the number of bathrooms available ger(Garrod & Willis 1992; Linneman 1980), and total living space (Carroll, Clauretie & Jensen 1996; Rodriguez & Sirmans 1994) all add value to residential properties.

Other research shows that property value is influenced by the existence of a garage or parking space/s (Forrest, Glen & Ward 1996). Garrod and Willis (1992) demonstrate that a single garage adds significant value to a property while a double garage is likely to add considerably more. Water heating system, central heating, fireplaces, may also contribute to the value of a residential property, although the extent to which they provide value is subject to the properties' broader geographical context (Garrod & Willis 1992; Li & Brown 1980; Michaels & Smith 1990).

Various studies show that increased building age negatively affects property prices (Clark & Herrin 2000; Kain & Quigley 1970; Rodriguez & Sirmans 1994). This is related to the additional cost incurred in maintaining older properties and their potential layout or design obsolescence (Clapp & Giaccotto 1998). On the other hand, older properties can improve their value due to their historical significance. In this regard, Clapp and Giaccotto (1998) suggest the operation of two counterforces involving the age coefficient: an obsolescence factor and a vintage effect that is subject to demand-side vicissitudes.

Studies concerning structural quality are under-represented in the literature, primarily due to the difficulties involved in objective measurement (Kain & Quigley 1970; Morris, Woods & Jacobson 1972). Nevertheless, Kain and Quigley (1970) find the condition of residential properties' driveways, walks, external structures, floors, windows and internal walls may all significantly influence their value. Later, research by Morris, Woods and Jacobson (1972), used a complicated approach to identify plumbing type, cooking facilities, refrigeration and lighting features to serve as proxies for property quality measurements. Although property quality differentials exist between houses most studies today rely on general neighbourhood characteristics as an indication of property condition.

Chau, Ng and Hung (2001) also note that builder's goodwill may influence property value. The authors suggest that properties constructed by large reputable developers are more likely to command a price premium per square metre of floor space than those built by companies of lesser reputation. The difficulty researchers face is incorporating this type of intangible attribute into a pricing model.

Accessibility/locational attributes

A property's value is partially conceived in terms of its fixed locational attributes. These are unchangeable, immoveable features (Follain & Jimenez 1985; Orford 1998) such as rail stations and highway entrances, which are usually quantified by an appropriate measure of accessibility. Other features of land use relating to locational attributes are often considered under the heading of neighbourhood characteristics (Dubin & Sung 1990).

Public transport accessibility is concerned with the ease of commuting to and from amenities such as employment locations schools and shopping centres and is generally measured by convenience or travel time compared with alternative transport systems (Adair et al. 2000; So, Tse & Ganesan 1997). Home-purchasers trade-off housing costs and the value of leisure time against the cost and time involved in commuting to desired amenities. In terms of rail infrastructure, the traditional view of accessibility concerns access to the CBD due to its role as the largest employment centre and its focus on public amenities. Property buyers thus consider rail stations as a desirable public good and are likely to pay more for properties nearby these amenities, because they provide access to the CBD. Therefore, ceteris paribus, the value of rail stations can be calculated by estimating property values relative to distances from the nearest station (So, Tse & Ganesan 1997).

Estimating proximity premiums that occur due to nearby transit access commonly involves hedonic modelling where the independent variable is distance to the transit station. This can be measured either in terms of travel distance or concentric distance rings (Cervero & Duncan 2002; Chatman, Tulach & Kim 2012; Duncan 2008). Studies from Bajic (1983) and Dewees (1976) use weighted average travel-time as an alternative to distance and others use savings, examining how travellers respond to a trade-off between time and cost, to explore willingness to pay for transit performance (Chen, Rufolo & Dueker 1998; Gatzlaff & Smith 1993; Lewis-Workman & Brod 1997; Nelson 1992; Wardman 2004).

Neighbourhood attributes

Previous empirical studies indicate that property price variations are significantly influenced by neighbourhood characteristics, which include both socio-economic factors and proximity to locational features (Dubin & Sung 1990; Linneman 1980). Social-economic factors comprise demographic profile (Garrod & Willis 1992; Ketkar 1992) and crime rates (Thaler 1978). Locational features include shopping facilities (Des Rosiers et al. 1996), schools (Clauretie & Neill 2000; Jud & Watts 1981) and employment zones (Debrezion, Pels & Rietveld 2007), as well as environment factors including the presence of views (Benson et al. 1998), traffic, airport noise (Espey & Lopez 2000; Feitelson, Hurd & Mudge 1996; Williams 1991) and other pollution factors (Chattopadhyay 1999).

The importance of neighbourhood attributes is demonstrated by Linneman's (1980) study, which finds that up to 50% of house price variation can be attributed to these factors. While the market does not explicitly value neighbourhood attributes, they may be implicitly estimated using hedonic pricing analysis, which compares house values in various locations with different socio-economic characteristics. Socio-economic variables are often proxied by scales representing a range of most desirable to least desirable neighbourhood characteristics.

Previous research reveals a number of different socio-economic variables employed in hedonic analysis. In some cases, proxies serve as representations of various local socio-economic characteristics. For example, Garrod and Willis (1992) use proxies to account for factors such as age distribution, population and employment density, and the number of households with two or more cars, which provides an indication of local affluence. Alternatively, Debrezion, Pels and Rietveld (2011) use neighbourhood income as a proxy for socio-economic influence on house prices. Areas with a higher average income are associated with superior location ambience and quality of amenities. Therefore, these areas are likely to generate higher house prices than areas with lower average income.

Many studies include estimates for racial mix. For example, in New Jersey Ketkar (1992) notes:

> …while population generally tends to be ethnically and racially mixed in urban areas, the majority (whites) tend to be sensitive about the proportion of non-whites (blacks and others) in their neighbourhoods. (Ketkar 1992, p. 641)

This implies some degree of discrimination against non-whites even though they may possess a standard of education and/or level of occupation similar to whites. Ridker and Henning (1967) also demonstrate that non-whites are inclined to pay significantly more for a residence in a white neighbourhood. Discrimination along these lines is perhaps less overt in Australia, where multiculturalism is considered an important aspect of community. However, some immigrants tend to concentrate in areas where culture is compatible. In this case, racial clusters are more likely a response to the locational preference rather than a direct cause of property value.

Home seekers are likely to pay a premium to avoid areas with high rates of crime or vandalism. Crime can be measured by rates of robbery, aggravated assault, vehicle theft and arson as a proportion of total residents (Haurin & Brasington 1996). Other studies use the percentage of school participation levels as a proxy for criminal activity (Li & Brown 1980). Research at Fresno County, California conducted by Clark and Herrin (2000) shows the coefficient of murder rate indicates property prices are lower in areas where the occurrence of murder is greater as a proportion of a location's residential population.

Environmental conditions may also influence residential property prices. For example, the inclusion of aesthetically pleasing public areas and amenities within housing estates tends to add price premiums to the local properties. Facilities may include parks, swimming areas and other types of recreational facilities (Mok, Chan & Cho 1995; Tse & Love 2000). A possible explanation is that these attributes are synonymous with quality of living. Similarly, home-seekers value a clean air environment, peaceful atmosphere and proximity of urban reserves (Tyrväinen 1997). Chattopadhyay's (1999) study of residents in Chicago confirms house buyers are willing to pay for reduced air pollution, while Leggett and Bockstael (2000) report that, in some circumstances, good water quality also increases house prices. On the other hand, the presence of waste sites can adversely affect property prices (Ketkar 1992; Kohlhase 1991). In Sydney, proximity to the harbour, bays and the coast are likely to be valued more than areas farther away (Abelson, Joyeux & Mahuteau 2013).

Research shows that noise from traffic may affect house prices values (Palmquist 1992). However, noise tolerance may differ among different groups. For example, Palmquist provides evidence that higher socio-economic neighbourhoods tend to discount property values, with each additional decibel of traffic noise, at a far greater rate than in neighbourhoods of the lowest social order. This suggests the very poor have a higher tolerance of noise, which is perhaps dictated by their ability rather than willingness to pay for improved conditions.

Noise and air pollution may have a contrary impact on the otherwise positive impact of public amenities. For example, airports may generate both positive and negative effects. Beyond a threshold 'disturbance' level, buyers tend to react adversely to close airport proximity. 'Disturbance' levels may be gauged by the recorded decibels at noise-affected locations. Using this technique, Espey and Lopez (2000) find a negative correlation between airport noise and house values. Interestingly, Feitelson, Hurd and Mudge (1996) find thresholds of noise tolerance apply beyond which home-seekers are unwilling to pay at any level. The present study does not present the opportunity to satisfactorily compare areas of high and low airport noise.[2] Therefore, locations of high airport noise have been excluded from the study.

Shopping complexes are locational factors that may influence property values. The effect of these facilities is commonly measured by distance to the amenity (Des Rosiers et al. 1996; Sirpal 1994). Proximity to shopping facilities can positively affect property values as a result of reduced travel time and costs, although residential properties that are very close may experience disamenity due to the negative effects of congestion and noise pollution (Sirpal 1994). Size of shopping complexes can also affect utility, which modifies the impact of the amenity on property prices. For example, Des Rosiers et al. (1996) claim that each additional shop in a shopping complex adds marginal value to properties within the vicinity of that complex.

Schools are another municipal service that potentially influences property values. Their impact is often measured in terms of student performance such as aptitude tests (SAT scores) (Ketkar 1992; Walden 1990) and/or expenditure outlay per pupil or student average costs (Ketkar 1992), which can influence the price of housing within school boundaries. Generally, higher school performance leads to higher nearby property values (Clauretie & Neill 2000; Jud & Watts 1981). Indeed, Clark and Herrin (2000) and Haurin and Brasington (1996) show school quality to be more important to family households than either crime or environmental issues. Standard hedonic approaches indicate a large degree of variability in house prices due to school quality. For example, Oates (1969) find that municipalities in Manhattan experience a median house price increase of 4.9% for every 1% increase in the log of pupil expenditure. On the other hand, Sonstelie and Portney (1980) discover a smaller effect when measuring the total cost of house occupation revealing a one-for-one relationship between pupil expenditure and the 'gross rent' of a residence. An alternative approach by Rosen and Fullerton (1977) involves test scores as a measure of school quality. In

[2] This is because none of the locations selected for this study fall within high noise flight path areas. There are no suitable data to study the effect of this variable.

that study, the authors find that house prices rise by 0.42% for each standard deviation improvement in results for reading and mathematics.

Later empirical studies involve significantly richer data sets designed to reduce endogeneity in modelling the effects of schools. For example, Brasington (1999) and Brasington and Haurin (2006) refined their analytical technique by including structural and neighbourhood characteristics, which were generally omitted from earlier studies. These studies revealed ratios of 0.5% property value increment for 1% improvement in pupil pass rates and a 7.1% increment for an additional one standard deviation in mean student test results.

A number of studies include employment zones as a locational characteristic. Traditionally research studies into proximity premiums factor the CBD as the largest employment zone. However, with growing polycentricism additional substantial urban employment zones are often now considered in these studies. Indeed, some studies demonstrate the countervailing influence of urban sub-centres in polycentric environments (Heikkila et al. 1989).

Other public amenities can lead to negative effects in relation to property values. For example, Huh and Kwak (1997) show that hospitals may have such adverse effects. Residential properties nearby hospitals, clinics and other health institutions often encounter noise and congestion within their vicinity. Similarly, places of worship potentially diminish neighbourhood property values if their presence increases traffic and noise from calls to worship (Do, Wilbur & Short 1994). The observations in the present research are largely unaffected by public health and religious institutions.

Finally, views are a locational attribute that often lead to higher property values (Benson et al. 1998). Numerous studies have shown that home-buyers are willing to pay a premium for views over lakes, golf courses, mountains, oceans and so forth (Benson et al. 1998; Cassel & Mendelsohn 1985; Mok, Chan & Cho 1995). There generally appears to be a strong correlation between floor level of residential apartments and premium paid due to a corresponding improvement in quality of view (So, Tse & Ganesan 1997). However, research also indicates the value of this amenity is often not uniform and depends on the quality and type of view. For example, Benson et al. (1998) find that properties with ocean frontages add 147% to their value, ocean views add 32%, and partial ocean views add 10%.

2.1.4.3 Property valuation: model specification

Grether and Mieszkowski (1974) are credited as pioneers of the hedonic price approach to residential property valuation. The authors apply various techniques to overcome weaknesses resulting from the model's definition, and in doing so provide the first notable application demonstrating its powerful predictive capability. Their study involves experimentation with different quantities of constituent property attributes to form a number of scenarios resulting in different house price estimations. The authors postulate that the value of a residential property is an additive function of its structural, locational and neighbourhood characteristics, which they describe as follows:

$$V_i = S_i x + L_i p + N_i y + e_i \qquad (2.9)$$

where:

V = property value

S_i = vector of structural characteristics

L_i = vector of locational characteristics

N_i = vector of neighbourhood characteristics

x, p, y = vectors of unknown coefficients

e_i = error term

The model includes structural characteristics such as floor size, building age, number of bedrooms, bathrooms and car spaces, and various utility feature inclusions represented by dummy variables. In addition, their study considers accessibility and neighbourhood characteristics comprising both positive and negative externalities that are likely to be capitalised in the cost of housing. These include local school quality, traffic flow, population density, racial mix and distance to town centre. The authors employ a semi-log estimating equation to identify a proportionate change in the dependent variable. This is expressed as:

$$\log V_i = S_i x + L_i p + N_i y + e_i \qquad (2.10)$$

Grether and Mieszkowski (1974) demonstrate the importance of functional form in model specification. There are a number of possible approaches in this regard, which are explored more fully in the following section. Grether and Mieszkowski rely on their priori knowledge of the variables to model likely behaviour. Taking this approach, the authors identify two nonlinearities to be explicitly included in the model. Specifically, the age of the house and its square are used as separate variables and occasionally the square of the house size is also considered.

The authors clearly demonstrate the excellent predictive power of the HPM. Their effort to explain the prices paid for family dwellings by examining the physical characteristics of the house and attributes of the location succeed in producing consistent and robust estimates. In addition, they show it is possible to estimate the magnitude of neighbourhood effects using a small number of controls for the nature of the dwelling. The authors conclude:

> While it may seem far-fetched to think of a housing market as or being so precise as to exactly decompose the price of any home into the values of its parts attributes, our results together with the results of others do suggest that it is definitely possible to measure the contribution to worth of many characteristics of single-family dwellings. (Grether & Mieszkowski 1974, p. 145)

2.1.4.4 HPM: functional issues

The choice of the model functional form is an important process required to avoid inconsistent estimations (Blomquist & Worley 1981; Goodman 1978). Although considerable attention has been given to the HPM there is surprisingly little guidance in regard to choice of functional form found in the literature (Butler 1982; Halvorsen & Pollakowski 1981). One method, indicated earlier in the review of the Grether and Mieszkowski (1974) study, requires an examination of the data to determine best fit. This process is often significantly assisted by a priori knowledge of the variables and their likely behaviour (Craig, Palmquist & Weiss 1998). However, most scholars do not have such insight in representing the relationship between commodities and their attributes. The suitability of modelling relationships such as linear, log-linear, double-log, and quadratic forms is instead often addressed through 'goodness-of-fit' criteria. The likelihood ratio is used to test restricted compared with alternative forms using Box-Cox transformations, to obtain the best possible data fit (Box & Cox 1964; Rasmussen & Zuehlke 1990).

On the other hand, Cassel and Mendelsohn (1985), suggest Box-Cox transformations possess some shortcomings. The problems relate to the numerous parameters estimated by the Box-Cox approach, which potentially reduces the accuracy of individual coefficients in the model by introducing unnecessary non-linearity. This may result in 'over-parameterized models with poor out-of-sample performance'. Hence, the model of best fit determined by the likelihood ratio test may not improve estimates of implicit attribute prices. Linneman (1980) also found Box-Cox transformation is not suitable for models with binary dummy variables as they represent discontinuous factors (see also So, Tse and Ganesan (1997)).

The choice of explanatory variables may also influence the performance of the HPM. The misspecification of variables can occur where irrelevant explanatory variables are included resulting in over-specification of the model, or where relevant explanatory variables are omitted leading to under-specification. While the addition of an irrelevant explanatory variable to the model does not cause bias, it may increase the variances of the estimated coefficients and therefore reduce the significance of other variables used in the model. On the other hand, an omitted relevant variable may cause bias as it can force the expected value of estimated coefficients included in the equation away from their true value, in terms of the population coefficient. This is because omitted and included variables are almost certainly correlated to some degree and the latter coefficients are likely to reflect some of the variation caused by the missing variables.

The difficulty facing researchers is that the HPM assumes the selection of appropriate variables that are mutually exclusive and the average effect of missing variables is insignificant. With the growing variety of data available, some recent researchers have resorted to 'kitchen sink' regressions (Black & Machin 2011) to improve the predictability of their models. However, in many of these studies, the inclusion of covariates is governed by the availability of data, rather than their relevance in explaining the dependent variable. This approach can prove problematic because the HPM becomes unwieldy and unstable with too many explanatory variables in the mix. Furthermore, the inclusion of many explanatory variables may lead to a greater likelihood of violating the mutual exclusivity principle. This is a condition that occurs when two or more independent variables are highly correlated resulting in an unintended overestimation of the coefficient estimator and thereby undermining the validity of *t-test* scores. For this reason, tests for multicollinearity have become an important diagnostic tool for researchers using the HPM.

Butler (1982) argues, that most, if not all HPMs are misspecified to some extent and therefore a parsimonious model is statistically more robust. Butler suggests only key variables that represent costly attributes and yield utility should be included in the estimation model. Mok, Chan and Cho (1995) concur that bias due to missing variables is found in a minority of cases and then with only negligible effects on the explanatory and predictive power of equations. In practice, the solution to omitted variables and potential bias of estimated coefficients is to ensure a homogeneous data set. It is this circumstance that justifies application of the HPM.

2.1.4.5 HPM: the property market, assumptions and limitations

The HPM makes several assumptions relating to its definition, which may affect the validity and interpretability of its results. The assumptions include equilibrium in the market, a perfectly competitive environment, access to perfect information and homogeneity in the housing market. The limitations of the HPM are most often related to these assumptions, which are commonplace in most economic models.

First, the assumption of market equilibrium means that households select their location-based on utility maximization and this is aligned with prices determined exogenously through a HPM (Dunse & Jones 1998). These prices are properly estimated only under equilibrium conditions. The HPM merely offers an estimation of that condition. However, there is an implicit assumption that the modelling captures equilibrium market values of attributes in the parameters of a regression. In reality, true market equilibrium is implausible due to imperfections in the property market. In addition, the implication that the implicit price of attributes is consistent through all locations and property types is questionable. Indeed, it is not always the case that the various housing attributes will offer a homogenous level of utility to all buyers.

Second, the HPM assumes the market operates within the context of perfect competition, which implies that no single participant is likely to influence property prices. This assumption is justified in most housing markets. With generally vast numbers of buyers and sellers active in the market place each transaction constitutes a negligible proportion of total market activity. The freedom to participate in the market without restrictions is also a reasonable assumption, subject to restrictions on access to capital.

Third, the model assumes access to perfect information. Although, arguably, perfect information is in all contexts unachievable, the assumption that market participants have sufficient information concerning product options, and prices is not unreasonable. Purchasing property involves a substantial capital outlay, which means buyers generally acquire a significant volume of information concerning the attributes of their intended purchase. For buyers, most relevant information is readily and freely available or available through industry professionals. Similarly, suppliers generally have access to critical knowledge of their business capabilities and market climate that enables investment decisions geared to maximizing profits.

Finally, the model assumes homogeneity in the housing market. This somewhat more controversial assumption is indeed arguable as the model ignores the possibility of market segmentation. Feitelson, Hurd and Mudge (1996) point out there is no theoretical requirement for segmentation of property markets in the application of the model. In practice, most markets feature several different types of market segmentation. Indeed, property markets are unlikely to be homogeneous (Adair, Berry & McGreal 1996; Fletcher, Gallimore & Mangan 2000), which means it is inappropriate to treat each geographical region as a single entity. Although most studies use locational boundaries based on political demarcation and often sub-divide these regions according to local socio-economic characteristics of residents (Michaels & Smith 1990), researchers must, nevertheless, consider what factors best differentiate target markets, and how best to identify their effects. On the one hand, too broad a geographical definition may lead to biased estimates due to improper aggregate sampling (Linneman 1980). On the other, too narrow a definition may give rise to imprecise estimates if the rationale used to classify segmentation lacks appropriate justification (Kain & Quigley 1975; Schafer 1979).

The complexities of sub-market composition and structure have been given greater attention in recent years with the introduction of a relatively new technique known as Geographically Weighted Regression (GWR). GWR addresses the issue of spatial effects regarding land value (Fotheringham, Brunsdon & Charlton 2002). It embodies spatial coordinates into the traditional global HPM in providing a set of local estimates, which enables identification of land value variations over space. The concept of GWR is discussed at greater length in Section 2.1.7. Both global and local models (HPM and GWR) are used in the present thesis.

2.1.4.6 Strengths of the HPM

The main strength of the HPM is its ability to estimate values based on actual choices. As an indication of value, property markets are relatively efficient in responding to information about consumer preferences. In addition, property data are generally reliable and readily available to provide the basis for explanatory variables used in the model. The marginal prices of imbedded attributes are reflected in the parameters estimated by the HPM. In this approach, the coefficients of the regression function are sufficient to identify home-seekers' preference structures. This means there is no need for invasive qualitative data collection involving personal particulars of both house buyers and suppliers.

There is no doubt the assumptions pertaining to the HPM involve some degree of simplification and abstraction from complex reality (Dunse & Jones 1998). Nevertheless, the model continues to be deployed extensively in studies that involve property markets (Ball 1973; Chau, Ng & Hung 2001; Debrezion, Pels & Rietveld 2007; Leggett & Bockstael 2000). Freeman (1979) observes:

> It must be acknowledged that there are many respects in which the actual data diverge from the theoretical ideal and in which the assumptions about the nature of the housing market and preferences are over-simplifications. But the question is not whether the model is perfect, but rather does it provide a usable vehicle for increasing our knowledge? (Freeman 1979, p. 171)

Freeman concludes that while the data are often inadequate, variables are often measured in error and the definitions of variables are seldom precise, the model remains valid for empirical purposes. Furthermore, recent advances in model definition, functional form and rigorous test improvements have delivered a credible tool for property value researchers. Today, the model 'is widely accepted for estimating the monetary trade-offs for quality attributes of private goods and spatially delineated environmental amenities' (Palmquist & Smith 2001, p. 116). The model is used extensively by the Reserve Bank of Australia (RBA) and the US Federal Government (Moulton 2001).

2.1.5 Variability in the rail accessibility-property price relationship: empirical evidence

Prior research indicates the extent that rail transit is capitalized into property values tends to vary considerably (Mohammad et al. 2013). Giuliano and Agarwal's (2010) review of relevant empirical research shows 'the literature does not establish unambiguously whether or not rail transit investments get capitalized in property values.' The inconsistency of the findings is believed to be partly the result of differences in the approach to research and the local conditions where transit investments are made. Duncan (2008) also highlights the difficulty of summarizing the available research by arguing that generalized conclusions are problematic owing to the variety of methodologies and contextual circumstances. However, other researchers argue that accessibility benefits are often capitalized into property price, which means close proximity to transit generally increases house values and rental costs (Wardrip 2011). This irregularity of empirical research involves factors that can similarly influence the present study's findings. The way this may occur is the subject of this section.

There are several studies that examine transit proximity premiums with significant variation in their findings. Diaz (1999) identifies a range between 3% and 40%, while Cervero and Duncan (2004) find premiums that range between 6% and 45%. Hess and Almeida (2007) conduct a review of rail systems revealing property premiums of up to 32% in some cases, and in others negative, or at best no discernible effect. Mohammad et al.'s (2013) comprehensive meta-study examines transit induced property premiums at residential, commercial and retail properties and the effects of metro, commuter and light rail at locations throughout Europe, the USA and Asia. Table 2.1 shows the effect is mainly positive, occasionally negative, and overall there is considerable variation.

Author(s)	Type	Rail system	Location	Model	Results
Voith (1991)	Res.	Commuter	Pennsylvania and New Jersey, USA	HP	3.8 - 10%
Laakso (1992)	Res.	Metro	Helsinki, Finland	HP	3.5 - 6%
Chesterton (2000)	Res.	Underground	London, UK	HP	71.1% & 42%
Bowes and Ihlanfeldt (2001)	Res.	MARTA	Atlanta, USA	HP	- 19% - 2.4%
Clower and Winstein (2002)	Res.	Light	Dallas, USA	AVG	7.2% & 18.2%
Bae et al. (2003)	Res.	Seoul's rail	Seoul, Korea	HP	0.13% - 2.6%
Cervero (2003)	Res.	Light/Comm	San Diego, USA	HP	46%
Yankaya and Clik (2004)	Res.	Metro	Izmir, Turkey	HP	0.7% & 13.7%
Du and Mulley (2007	Res.	Light	England, UK	GWR	- 42% - 50%
Pan and Zhang (2008)	Res.	Transit	Shanghai, China	HP	1.1% & 3.3%
Bollinger et al. (1998)	Com.	Light	Atlanta USA	HP	- 7%
Weinstein and Clower (1999)	Retail	Light	Dallas, USA	AVG	4.6%
Cervero (2003)	Com.	Light/Comm	San Diego, USA	HP	71.9 - 91%
Cervero and Duncan (2002)	Com.	Light/Comm	Santa Clara, USA	HP	23% & 120%

Table 2.1 Sample of empirical study variations
(Mohammad et al. (2013) augmented)

The following summary lists the mediating factors in the literature that are likely to result in variations of transit proximity premiums between locations. Empirical studies show that the impact of rail infrastructure on property values may vary spatially due to the heterogeneity of research locations. The spatial issues examined in the literature can be classified into five main categories: geo-cultural differences, accessibility to the CBD, competition from motorways, proximity to rail stations and the effect of *place*.

2.1.5.1 Geo-cultural differences

Geo-cultural difference is an important factor contributing to the variability of estimated rail induced property value change. Mohammad et al. (2013) show that research conducted in different continents can produce significant variations in the perceived value of transport accessibility. The studies indicate higher percentage changes in property values for cities in Europe and East Asia compared with those in North America. The authors suggest that a possible explanation is the car-oriented culture that typifies the latter. The literature also indicates that, overall, values are higher in congested zones compared to those with less traffic activity (Clower & Weinstein 2002).

2.1.5.2 CBD connectivity

The CBD is often a major focus of amenities and economic activity, which implies that CBD transit access is likely to influence suburban proximity premiums. A transport network that provides accessibility to the CBD is generally found to have a positive influence on nearby residential housing prices (Palmquist 1992; Ridker & Henning 1967). In a study of sorting in the Philadelphia urban area, Voith (1993) found that residents with direct commuter rail access to the CBD incur proximity premiums compared with those in similar neighbourhoods without direct rail access. However, Voith suggests 'the estimated value of CBD accessibility fluctuates with the economic health of the city' (Voith 1993, p. 363), indicating the CBD economy is an important contributing factor to the variation in property valuation due to rail infrastructure.

Empirical studies identify different results regarding the relationship between CBD proximity and the impact of rail stations on nearby property prices. For example, the Bowes and Ihlanfeldt's (2001) study suggests that rail stations distant from the CBD have a higher travel time and cost, and therefore may have a higher impact on property values than locations closer to the CBD. In contrast, Mohammad et al.'s (2013) meta-analysis suggests CBD proximity has little effect on price variations.

The types of urban layout can also influence the estimates of rail impact. For example, the importance of CBD accessibility is likely to be greater in monocentric than in polycentric urban environments. A valuable contribution to our understanding of this phenomenon is Heikkila et al.'s (1989) research of the Los Angeles metropolitan area. This study shows that eight Los Angeles sub-centres register a statistically significant influence on residential property values while the price-distance function for the CBD produces an unexpected negative sign. This implies the existence of multiple locations offering accessibility to large employment precincts and other amenities such as shopping, educational and recreational facilities diminish the value of CBD-focused transport. The authors state:

> …not only does accessibility to subcentres in Los Angeles influence residential land values, but their inclusion totally swamps any impact that CBD accessibility might appear to have in a less comprehensive specified study. (Heikkila et al. 1989, p. 222)

The authors claim 'this is powerful evidence in support of the need to discuss US metropolitan areas in polycentric terms and the case for abandoning the standard but irrelevant monocentric model' (Heikkila et al. 1989, p. 230).

2.1.5.3 Motorways

The literature reveals that proximity to motorway access represents an important competitor to rail transport (Bollinger, Ihlanfeldt & Bowes 1998; Voith 1993). Damm et al. (1980) confirm that the benefits of motorway facilities are also capitalised in property values, which dilutes some of the value-adding potential of rail investment. Further, rail infrastructure tends to promote the attractiveness of motorways by absorbing a portion of the commute traffic. In fact, research demonstrates that costs associated with both private and commercial vehicles tend to decline in urban areas as rail network mileage expands (Winston & Langer 2006). Baum-Snow, Kahn and Voith's (2005) study finds significantly lower comparative commute travel times in cities with rail transit, compared with similar cities that rely on automobile and/or bus transport only.

The evidence suggests the availability of rail and motorway access may also have a complementary relationship. Urban traffic congestion tends to maintain an equilibrium position in which additional traffic encourages commuters to seek alternative means of transport. Therefore, the availability of quality travel alternatives maintains the traffic congestion equilibrium and increases the overall volume of commuter traffic. This is supported by a range of studies that confirm the marginal cost of door-to-door travel times for motorists tend to converge with those of rail transport users (Lewis & Williams 1999; Litman 2011). This suggests that, given equivalent accessibility, the effect on property values is likely to be shared in proportion to the demand for each mode of transport.

2.1.5.4 Distance to the rail station

Typically, scholars agree that rail transport infrastructure provides economic benefits through accessibility. The locations with better public transit access tend to spend less on transport which makes housing more affordable (Kilpatrick et al. 2007). This suggests that reduced travel time is likely to be reflected in property values nearby rail stations (Hess & Almeida 2007). The estimates of rail impact indicate the extent and magnitude of proximity premiums are generally relative to the distance from rail access points. The research also suggests that areas close to rail stations generally experience heightened residential demand due to the variety of amenities offered (Bluestone, Stevenson & Williams 2008). Conversely, disamenity may occur from being too close to rail transit access points (Cervero 2006). Therefore, these benefits are greatest near, but not too near, rail stations and diminish with increasing distance from the station. The following diagram illustrates the effect of proximity to the node on the rent slope.

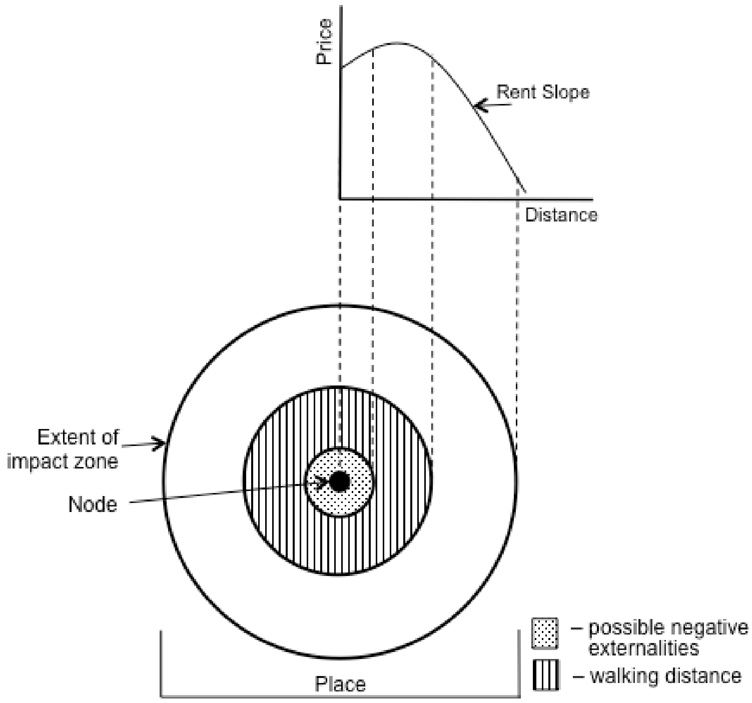

Figure 2.1 General effect of proximity on property premiums

A number of studies reveal that locations immediately opposite, or in very close proximity to train stations or rail lines are often perceived as affected by noise, pollution and crime, and property values are discounted accordingly (Diaz 1999; Hui, Ho & Ho 2004; NEORail II 2001). However, it is important to note this is somewhat dependent on the type of station, for example whether it is ‘walk to’, ‘drive to’, and above or below ground (Bowes & Ihlanfeldt 2001; Kahn 2007). Away from the immediate station area, residential property values are likely to improve up to an optimal point, followed by proximity premium decay (Chen, Rufolo & Dueker 1998; Debrezion, Pels & Rietveld 2007). An earlier study by Dewees (1976), that examined the relationship between rail travel costs and residential property values, reported a positive effect of proximity to subway access within a one-third of a mile radius, or approximately 530 metres, from the access point. Similarly, Damm et al. (1980) identified a statistically significant relationship between land values and anticipated rail access in Washington, DC, stating that ‘in all the final models, increasing distance to the station was associated with lower property values [and] the effect of distance seems to decline quite rapidly’ (Damm et al. 1980, p. 331). The greatest impact of rail connectivity on commercial and residential property values is generally considered to lie within a radius of approximately 1,000 metres (RICS 2002). The present study estimates the effect of rail on property values within the impact area.

2.1.5.5 The effect of 'place'

New and existing rail transit infrastructure generally has a positive effect on property values, although its impact may vary substantially according to context. Market circumstances of different locations may lead to different transit induced proximity premiums. For example, areas with strong property markets and efficient transport services are likely to experience higher price premiums than areas with average market conditions and poor transport services (Wardrip 2011).

The perceived value of housing sites nearby rail stations is subject to the extent that accessible rail and other nearby local amenities satisfy community needs. For example, Debrezion, Pels and Rietveld (2011) found the existence of local large-scale employment zones present a key variable explaining different locational proximity premiums. Similarly, proximity premiums generated by local shopping complexes are to a large degree influenced by their size (Colwell, Gujral & Coley 1985; Sirpal 1994). It is also important to note that a strong positive reputation of local schools may enhance the desirability of a neighbourhood (Bayer, Ferreira & McMillan 2007; Black 1999; Brasington 1999; Gibbons & Machin 2006; Kane, Riegg & Staiger 2006; Oates 1969; Rosen & Fullerton 1977). The availability of employment, shopping, education as well as social, cultural and entertainment facilities generates a community proximity premium commensurate with the quality, size and variety of its aggregate amenities. Collectively, the commercial complex surrounding rail stations is known as *place*. This concept and its influence is discussed further in Section 2.1.6.2.

2.1.5.6 Demographic characteristics

Property values, derived from proximate causal relationships with rail infrastructure, may also be influenced by a locality's demographic characteristics. For example, previous research shows that rail station proximity premiums are higher in lower-income residential neighbourhoods compared to higher-income neighbourhoods (Bowes & Ihlanfeldt 2001). This suggests that poorer residents rely more on public transport and attach greater value to living nearby train station. Similarly, Gatzlaff and Smith (1993) confirm that variations in empirical research results can be influenced by local demographic factors. Voith (1991) also found that residents in suburban areas with efficient commuter rail access tend to own fewer cars, compared with those in similar neighbourhoods without a rail service, which may lead to greater dependency on rail transit irrespective of demographics. The relationship between rail and demographic profile is discussed at greater length in Section 2.2.

2.1.5.7 Type of land use

Most studies focus on residential properties in relation to the impact of transit infrastructure and very few examine the effect on commercial property values. Nevertheless, research provides a range of evidence that land use may account for some variability in the impact of rail stations on nearby property values. For example, railway stations generally have a larger effect on residential properties than on commercial properties (Cervero & Duncan 2002; Weinstein & Clower 1999). However, the impact on commercial property values tends to be greater than residential properties nearby station sites. (Cervero & Duncan 2002; Debrezion, Pels & Rietveld 2007; Weinstein & Clower 1999). Debrezion, Pel and Rietveld's (2007) meta study reveals commercial properties within a ¼ mile radius from a rail station are 12.2% more expensive than residential properties. However, residential properties that are farther away from rail station sites attract higher premiums than commercial properties.

A study by Weinberger (2001) of the Santa Clara County's light-rail system in northern California found that commercial properties within a half-mile of rail stations incurred a rent premium, and was greatest within a ¼ to a ½ mile away. A second study of the Santa Clara region by Cervero and Duncan (2002) also found commuter rail led to higher commercial property values compared to light rail, which is contrary an earlier result found by the same authors for residential properties in the same region (Cervero & Duncan 2002).

2.1.5.8 Type of rail investment

Research shows that different forms of rail service have different impacts on property values. For example, several studies indicate that commuter/metro rail stations have a relatively greater impact on residential property values than light rail stations (Cervero & Duncan 2002; Debrezion, Pels & Rietveld 2007; Dziauddin, Powe & Alvanides 2015; NEORail II 2001). Estimates by Mohammad et al. (2013) show commuter rail has approximately 24% greater effect on property values compared with light rail, which the authors attribute to the idea that commuter rail offers greater benefit to travellers at longer distances, while light rail has greater relevance at shorter distances. Similarly, research from Landis et al. (1995), Lewis-Workman and Brod (1997) and Brinckerhoff (2001) each show that heavy rail has generally a greater influence on property values than light rail, which they attribute to better service frequency, scope and speed compared to light rail networks.

The impact of rail infrastructure on property values may also differ depending on the level of service and its perceived benefit to local communities. As shown earlier, Debrezion, Pels and

Rietveld (2007) explain that different valuations of rail services may also be attributed to rail operation frequency, network connectivity, coverage and other service efficiencies. For example, Chau and Ng (1998) find electrification of the Kowloon-Canton Railway improved the speed of the rail system and produced an uplift of property values along the transport route. Similarly, Yiu and Wong (2005) demonstrate property price increases due to a new rail tunnel which delivered significant savings in transport cost and time.

Apart from service enhancements to existing rail infrastructure it may reasonably be expected that an entirely new rail station is likely to provide even greater utility to community residents and therefore a larger impact on property prices. For example, Grass (1992) identified a considerable 19% increase in nearby property values as a result of newly opened metros in Washington, DC. However, it should be noted that community valuation of rail transit may vary overtime as the rail network evolves and accessibility to alternative transportation modes change.

2.1.5.9 The effect of technology

Some studies identify technology as a moderating factor influencing the perceived value of rail infrastructure. For example, Gatzlaff and Smith (1993) find that…

> …in a decentralized city the recent addition of a fixed rail system appears to have had only a marginal impact on residential property values, indicating that the system has had little effect on accessibility. Gatzlaff and Smith (1993, p. 66)

The authors suggest this is possibly the result of advances in communications technology and computer functionality that enable companies to be far more ‘footloose’ in regard to their locational choice.

Similarly, from the commuter perspective, the reported incidence of larger numbers of people working from home and growing use of the internet to purchase goods obviates the need for closer access to the workplace and shopping centres. In this case, the perceived value of rail access is diminished, and the extent to which this cohort is significant in a community will tend to moderate the influence of rail investment on property values.

2.1.5.10 The impact of methodological choice

Some variation in property value change estimates may be attributable to the application of different methodological approaches. Four main empirical methods are used in the literature: the predominant HPM, GWR, differences-in-differences and direct comparison by average value changes. Mohammad et al. (2013) observed that estimates are generally consistent in size across methods, apart from the average comparisons of values, which produce estimates significantly lower than regression models. The authors also note that studies using cross-sectional data tend to report lower estimates than those using panel or time-series data, as is the case with semi-log and double-log models compared with linear models. The authors do not specifically address the reasons for these anomalies. However, they suggest some instances of estimate variation, due to methodology, may result from limited sampling and that this requires more comprehensive analysis to confirm and explain their findings.

2.1.6 Alternative approaches to estimating the impact of rail transit accessibility

Most empirical studies concerning the impact of transit accessibility examine its effects in terms of property valuation rather than land use or demographic transition, which is probably due to the relative ease of obtaining data relating to the former (Landis et al. 1995). It is pertinent to note at this point that the term 'accessibility' used here has been widely debated in transit planning literature for many years (Handy & Niemeier 1997; Morris, Woods & Jacobson 1972; Zhu & Liu 2004). For the purpose of the present study 'accessibility' adopts Du and Mulley's definition where the term refers 'to the ease with which the land use and transportation systems enable individuals to reach activities or destinations' (Du & Mulley 2012, p. 52).

Estimating the effect of rail accessibility on property values often focuses on transport proximity. In this regard, there are two main analytical approaches, involving either pre/post analysis or the separation of property attribute effects, both using the HPM. The first study method examines property prices at locations before and after the introduction of new transport infrastructure. The second approach compares residential prices nearby transit with prices farther away, at a given point in time, to separate the effects of property and neighbourhood characteristics from the impact of location.

2.1.6.1 Pre/post studies

'Pre/post' studies tend to be less common in the literature because they require access to less readily available longitudinal data (Chatman, Tulach & Kim 2012). However, when these data are available pre/post studies can deliver a worthwhile assessment of the influence of new rail infrastructure on nearby property prices providing there are no other undetected influences that can affect results. The process involves estimation of the difference in property values following an event affecting rail services at an impact area, compared with a control location. The selection of impact and control locations that are economically stable, apart from a change to rail services in the impact area, enable researchers to isolate the effect of rail investment on property values without the need to account for other locational attributes. The difficulty of finding suitable control counterparts for impact locations in ensuring reliable analysis means some researchers opt for comparison of inner and outer concentric rings emanating from treated areas.

Chesterton's (2000) study typifies the pre/post approach. The main aim of the study is to investigate the impact of London's Jubilee Extension (JLE). The observations are divided into four individual catchment areas, which reflect recognizable market segments along the JLE. The study examines, within these geographical segments, three sub-classifications including neighbourhood effects, property specific characteristics and transport effects:

Neighbourhood effects

Each postcode in the catchment areas is classified according to one or more of the following segments:

Urban regeneration area
Public housing area
Conservation area
Areas with a waterfront view.

Property specific characteristics

This investigation takes account of property specific characteristics, including size and age of residences, availability of a garage, central heating, and building type classified as either flats or terraces. These property characteristics are also classified in terms of:

Dwelling type and
Dwelling group.

Transport effects

Transport effects are measured in terms of the walk time from each transaction in the sample to the new JLE station in each enumeration district. Chesterton employs the HPM to isolate and measure the impact of this effect on the overall price level. The author divides the overall analysis period into three sub-periods:

1989 to 1993 – baseline period, prior to announcement
1994 to 1997 – anticipatory period (main construction)
1998 to 1999 – pre-opening period (end of construction and opening).

This approach allows estimating the strength of the relationship between the explanatory variables and transaction price levels over time, including changes to the property price premiums through different periods of the JLE development.

Chesterton follows most similar rail impact studies that have a spatial dimension and focuses on property transactions in catchment areas within 1,000 metres from each station. The study also considers a wider sphere of influence, described as a 'buffer zone', up to 3,000 metres from each JLE station. This assumes that property values are 'expected to decay from core' to the periphery of station influence. Finally, all property price transactions are standardized using an appropriate quarterly property price series index. This estimates real prices unaffected by market vicissitudes and facilitates meaningful comparisons of inter-period activity.

The results of Chesterton's JLE study have important implications for formulating the approach to be used in the present study. Chesterton clearly demonstrates the importance of location-based factors reflected in the neighbourhood segment variable. The author shows these factors had by far the greatest influence on house prices, registering up to 90% of the explained variance of property prices during the study period. In contrast, the walk time or distance from a Jubilee Line station, which is significant in models for three of the four catchment areas, explains only a small percentage of variation in the price data. However, for the three catchment areas with significant coefficients, the sign of each is negative over all time periods. This implies property prices fall with either distance or walk time from the rail stations. Overall, these results indicate that property re-valuation effects are compartmentalized and that location-based factors are crucial to understanding the full impact of rail infrastructure investment. This highlights the fact that modelling such effects must take account of these factors.

Another important matter raised in the Chesterton study concerns the problem of masked shocks unrelated to the focus of the study. Chesterton reports London's property market is continually subject to shocks, of different origin and different degrees of impact, in both time and space. 'At its simplest, the JLE has been one of these' (Chesterton 2000, p. 5). Some masked shocks may increase residential property supply, which may neutralize any positive effects associated with the JLE. On the other hand, area-based shocks such as regeneration initiatives may exaggerate the impact of the JLE by adding to the rise in property values. The author reveals that:

> …the scale of JLE and the complexity and diversity of the areas through which the line runs, linked with the myriad of processes of change that operate in London, added to the difficulty in isolating, let alone quantifying, the impact of the extension. (Chesterton 2000, p. 4)

Finally, the author suggests that some of the influence associated with the introduction of the JLE is yet to be revealed. Chesterton believes the degree of variability between regions suggests that the 'JLE is one of many shocks interacting on the residential market at different times' since the Parliamentary Bill to begin construction was announced:

> It could be suggested that it is more likely to have the most impact post-opening as individual purchasers' travel the Line and begin to expand their spatial awareness to consider the opportunities offered by JLE in terms of improved accessibility. (Chesterton 2000, p. 6)

Chesterton concludes:

> We believe that our findings indicate that the JLE will result in more than a corridor of movement, being a corridor of rejuvenation and revitalization, albeit with differential impacts in time and space. However, analysis of the after-opening period is needed to identify and potentially quantify more clearly the likely contribution of JLE to what is a complex process. (Chesterton 2000, p. 8)

Chesterton highlights the difficulties associated with isolating the impact of rail induced shocks. In fact, Chesterton considered that a critical requirement of the study should be based on the analysis of sufficiently 'robust data to allow the identification and quantification of any impact' (Chesterton 2000, p. 18). Hence, the author employed a number of variables in the analysis to account for the effect of all potential shocks. The variables are both internal and external to the property market operating at different levels, such as cyclical movements in the property market and area-based regeneration initiatives.

Chesterton's work clearly demonstrates the elevated complexity of the research task using the pre/post methodology. The approach raises some doubts regarding whether the true impact of transit investment can be captured using this technique. There is also an issue with the typically limited timeframe of these types of studies and their ability to capture the effect of new rail once it has been fully factored as a transport option for local residents. This suggests firstly, that pre/post studies are more suitable if the impact of new transit investment can be completely isolated from other events that influence proximity premiums; and secondly, this type of study has limited value unless the timeframe is sufficiently long to capture the full effect of rail investment.

2.1.6.2 Separation of effects

Studies using the separation of effects rely primarily on cross-sectional data. This has the advantage of enabling investigation of locations beyond those that have recently experienced an upgrade to transit infrastructure. The process requires careful isolation of other 'attractors' that may influence proximity premiums. However, unlike pre/post, intermittent masking shocks that occur over significant periods of time are largely irrelevant since observations are made at only one point in time.

Perhaps the most ambitious study using the separation of effects to isolate the impact of rail infrastructure is offered by Debrezion, Pels and Rietveld (2011). The authors' primary aim is to examine the relative influence of commuter rail transport accessibility compared with all other location attributes. In this study, an HPM is estimated based on more than 60,000 property sale transaction data from the Netherlands. Sales data are sourced from three regions: Amsterdam, Rotterdam and Enschede, representing the three main metropolitan centres in the Netherlands. Rail transit accessibility is measured both in terms of distance to railway stations and an index of quality of transit services at the stations. In each case two rail stations are considered, the closest and the most frequently chosen station. Also included is a road accessibility measure, which is considered potential competition for rail transit.

Debrezion, Pels and Rietveld's model specification includes a variety of explanatory variables covering housing physical structure, rail transit accessibility and environmental factors. Those representing the physical attributes of housing include the surface area of the living space, age of the structure, number of rooms and number of bathrooms, as well as access to a garden and garage, and the heritage status of the property. Railway accessibility has two components that incorporate both local accessibility and service quality. Local accessibility measures the proximity of properties to rail stations estimated by calculating the Euclidean distance between the two points. The service quality is a 'regional accessibility component' based on a 'derived railway service quality index' (RSQI) and accounts for the level of transit services, at each station.

Service levels are divided into four aspects, each with implications for commuter travel time. The first, estimates the service frequency provided by each station. The rail service quality index assumes a shorter waiting time indicates a higher level of service. Second, the index estimates rail station connectivity in relation to other stations in the network, which accounts for the number of direct rail connections offered at each station. Third, the estimations include the relative position of a station in the network, which relates to the distance between stations and the speeds at which the trains operate. This suggests proximity to traveller destinations increases the attractiveness of a station as a departure point. Finally, an estimate of the costs (fares) of rail travel is included in the quality of service index.

Debrezion, Pels and Rietveld also estimate the influence of proximity to alternative rail access. The authors argue that a large proportion of rail travellers use stations that are not nearest to them. To explore this issue, the authors analyse the effect of rail transit accessibility on property values for two stations: the nearest and the most frequently used station. The nearest station is determined using a Geographical Information System (GIS) and identification of the most frequently chosen station is based on surveys conducted by Dutch Railways (Nederlandse Spoorwegen).

The authors also identify the proximity of major employment centres and institutional amenities as important factors that influence house prices. The inclusion of all employment centres with 100,000 jobs or more acknowledges the importance of decentralization and increasing polycentricism in recent urban development. The location of schools and hospitals are also considered in Debrezion et al.'s model. The proximity to employment centres is measured by the weighted average distance, and to schools and hospitals by its Euclidean distance.

Neighbourhood physical and demographic characteristics are also considered in Debrezion et al.'s model. The study investigates the influence of 14 land use types at the postcode local level. In addition, the socio-economic composition of the population is represented by estimates of average household income and the percentage of foreigners in the postcode of property sales transactions.

The hedonic pricing methodology adopts a semi-logarithmic specification, where the dependent variable is the natural logarithm of residential property sale prices. This provides robust estimates and convenient coefficient interpretation. The data takes into account both temporal and spatial effects. The study examines a period of 5 years, which tests changes in the value attributed to proximity. The data also considers both inflation and real value changes across the time-period and there are regional dummies representing the municipality level to account for spatial effects.

The data are organized in a cross-sectional pattern. The general structure of the model is given as follows:

$$ln(P) = B + B'X + B'X + \cdots + B'X + e \quad (2.11)$$

Expanding to:

$$ln(TranPrice_i) = a + b'_{HC} \times HouseChr_i + b \times ln(Raildist_i) + b_{RSQI} \times ln(RSQI_i) + b_{railline} \times Drailline_i + b_{hwline} \times Dhwline_i + b_{hw} \times ln(Djobs_i) \times ln(Dschool_i) + b_{hw} \times ln(Dhospital_i)\ b'_{Neigh} \times Neighb_i(2)\ + b'_{Region} \times Dregional_i + b'_{time} \times Dtime_i + e_i \quad (2.12)$$

where:

$TranPrice_i$	represents the transaction price of house i;
$HouseChr_i$	is a vector of house characteristics variables including house type, surface area, total number of rooms, number of bathrooms, presence of garages and gardens, gas heaters, fireplaces, 'monument status' of the house and age of the building. Some variables are continuous, and others are represented by dummies. Logarithmic transformation of the continuous variables is used in the estimation.
$Raildist_i$	is the Euclidean distance between house i and the local rail station.
$RSQI_i$	is the quality indicator for a railway station.
$Drailline_i$ and $Dhwline_i$	are dummy values that indicate if a house is located within 100 metres of a rail line or highway, respectively. Dummy variables representing distances within 100 metres from a rail line or highway are included to capture 'the nuisance effect' from the railway and highway, respectively.
$Djobs_{i,}$ $ln(Dschool_i), Dhospital_i$	provide the distance to jobs, schools and hospitals.
$Dregional_i$	are regions proxied by municipality dummy variables.
$Dtime_i$	represents year dummies accounting for the temporal effect.

A total of 82 explanatory variables are used in the HPMs. Of these, 33 relate to physical house attributes, 16 neighbourhood characteristics, 5 to time series and 21 to municipality factors. The remaining 7 variables relate to different accessibility features including proximity to rail and highway access and distance to public facilities such as job centres, hospitals and schools. The municipality dummies represent various geo-political factors that may affect house values. Therefore, the impact of rail stations has been corrected for municipal features.

Debrezion, Pels and Rietveld's study shows the elasticity of distance to the nearest railway station in Amsterdam is –0.01, while the elasticity of the RSQI is –0.036. The latter coefficient sign is counterintuitive to expectation. For Rotterdam, both variables are found to be insignificant. For Enschede the elasticity of distance to the nearest railway station and the RSQI are –0.02 and 0.04, respectively. This metropolitan area has a significant effect and the expected sign. In Amsterdam, the elasticity of distance to the most frequently chosen station and its RSQI are –0.012 and 0.118, respectively. In Rotterdam, distance has no significant effect. However, for Enschede the elasticity of distance to the most frequently chosen station and its RSQI are –0.025 and 0.030, respectively.

The results show regional differences can affect the impact of rail accessibility on real property values. In the less urbanized Enschede, the effect of the nearest and the most frequently chosen station are most often the same. On the other hand, in highly urbanized Amsterdam the most frequently chosen railway station has a large impact on property values, which implies the most frequently chosen station is not necessarily the nearest. This is also positively influenced by rail service quality. Other findings show that proximity to a rail line or highway has no consistent negative noise effect. Also, the elasticities of distance to job centres for Amsterdam and Rotterdam are –0.042 and –0.036, respectively, while there is no significant effect in the Enschede district.

In general, the results show rail accessibility is a function of distance and service levels at rail stations. The choice of station is affected by service quality, which includes network connectivity, service, frequency, coverage and station facilities. Therefore, it is possible for property prices to respond more positively to stations farther away than to less important stations located nearby.

It is interesting to note other aspects of Debrezion, Pels and Rietveld’s research. For example, the authors highlight the importance of property structural features. The research suggests, a unit increase in the number of rooms leads to a 31.3%, 30.7% and a 22.0% increase in property value, for Amsterdam, Rotterdam and Enschede respectively, all at a 99% level of confidence. The coefficients are also highly significant for other structural attributes such as number of bathrooms, number of garages and building age. This evidence supports other studies in the literature which demonstrates the importance of including physical structure in the modelling process. On the other hand, the impact of certain socio-economic features is far more problematic. For example, Debrezion, Pels and Rietveld’s study shows that while the percentage of foreigners is significant in all regions, its sign is not consistent between regions. Similarly, the log of average income has been excluded from some tables, presumably due to a lack of significance.

Although Debrezion, Pels and Rietveld’s separation of effects model achieves a high R^2 value (over 80% for all models), it is important to note that there are other considerations that may affect the model’s performance. For example, simultaneously investigating a large number of predictive variables can affect model integrity. Specifically, the model’s lack of parsimony in an attempt to capture every conceivable factor in determining property values may have given rise to serious econometric issues. The authors note, ‘it may be argued that the inclusion of a huge number of variables increases the risk of multicollinearity' (Debrezion, Pels & Rietveld 2011, p. 1007). However, the authors find no evidence of a systematic relationship between the main variable of interest, rail accessibility, and the other control variables. There is also no discussion regarding the problem of multicollinearity and other findings of the research.

The other issues that may affect the model's performance relate to the study's scope and undisclosed variables that may compete with station influence. For example, the inclusion of several spatially segmented markets may affect regional comparisons (Andersson, Shyr & Lee 2012). The problem concerning undisclosed locational factors that compete with the influence of rail accessibility on property values is a common difficulty faced by researchers in efficiently isolating locational attributes that are spatially correlated with the study's point of reference, in this case the train station. This is an important matter well recognized by Vessali (1996), who warned against placing unrealistic expectations on the model.

An additional factor excluded by Debrezion, Pels and Rietveld's (2011) study concerns the economic importance of the various rail hubs. In evaluating the broader impact of rail accessibility on property values it is important to consider the complex notion of a rail station as both a *node* and a *place*, as distinguished by Bertolini and Spit (2005). Urban rail stations as *nodes* refer to a 'point of access to trains' and other transit networks. At the same time, rail stations are also features of a *place*, comprising the surrounding location along with its infrastructure, amenities and residential properties. As *nodes*, rail stations produce positive externalities by providing accessibility to other locations for employment, shopping, professional services, entertainment and so forth. As *places*, the areas surrounding rail stations may be subject to both positive and negative externalities. For example, high levels of commuter movement linked with rail stations produce positive externalities by encouraging retail activities in these areas and are often the proximate cause of commercial and subsequent residential developments. However, rail stations may also emit negative externalities due to traffic congestion, noise, pollution and problems associated with crime, particularly in areas immediately adjacent to rail stations (Bowes & Ihlanfeldt 2001; Loukaitou-Sideris, Liggett & Hiseki 2002).

Bertolini and Spit's (2005) theoretical framework suggests the perceived value of a rail station, as the nodal point of transit access, may be influenced by the station's surrounding *place*. Indeed, it is likely that, given the exclusion of a variable relating to the commercial size and complexity of locations surrounding rail stations, the influence of rail transit on property values is at times under and sometimes over-estimated when using the Debrezion, Pels and Rietveld (2011) approach. It is not only the type and quality of rail service that influences property values, but local attributes are also important. Therefore, understanding the effects of spatial heterogeneity is an important factor in isolating the true effect of rail transit access on property values.

The problem of spatially correlated locational attributes can be resolved. The challenge is to devise a variable that satisfactorily represents the commercial size and complexity of the *place* associated with rail transit locations. This involves estimating the effect of different types of locations on property valuations. Ceteris paribus, this reveals whether location types moderate the influence on property values resulting from new and existing rail investment. This important form of analysis has been largely absent from previous studies and an attempt is made to address this in the present research.

Another potential issue with the Debrezion, Pels and Rietveld study is that the focus area includes multiple metropolitan areas. This occurs if variables are likely to vary spatially. That is, where price-determining effects are expected to vary over space, which may lead to biased estimates of attribute effects (Helbich et al. 2014). Restricting analysis to one metropolitan region avoids a major criticism of Debrezion, Pels and Rietveld (2011) approach, which aggregates different urban regions (Andersson, Shyr & Lee 2012).

The present study also aims to identify other aspects of spatial variability in relation to rail accessibility. Local estimates reveal patterns that may emerge from global modelling and tests the uniformity assumptions relating to causal relationships. Local modelling is therefore an important supplemental tool that can be used to enhance the value of the global model findings. For this study, a local modelling technique known as GWR is employed to identify these patterns.

In summary, the Debrezion, Pels and Rietveld (2011) model provides the basis for a suitable approach to address Stage 1 of the research problem in the present research. Specifically, it enables the isolation of property value effects due to rail accessibility at locations with long established rail stops (mature rail stations). However, there are three important differences that must be adopted to improve the value of the research findings. First, the present study can enhance the integrity of its results by avoiding over-populating the predictive variables used in residential house price modelling. Second, the present study employs variables that distinguish *node* and *place*, which helps clarify the value of rail accessibility compared to other attractors that contribute to proximity premiums. Finally, this study identifies and explains other spatial variability that may occur within the focus area.

2.1.7 Local spatial modelling

As discussed, this study employs the use of the GWR methodology to assess the interdependency of spatially defined factors and rail transport accessibility in the process of estimating rail induced proximity premiums. In doing so, the research demonstrates the application of a relatively new methodological approach, which has become increasingly recognised as a valuable tool to account for the spatial nature of data. The following sections provide a brief review of local spatial modelling techniques and, in particular, the application of GWR.

2.1.7.1 Local versus global spatial analysis

Fotheringham, Brunsdon and Charlton (2002) explain that local statistics are spatial disaggregations of global statistics. If a model is calibrated with equally weighted data across a region it is defined as a global model yielding global parameter estimates, while a model calibrated with spatially limited data is defined as a local model yielding local parameter estimates. This means local estimations reveal variations across space whereas global estimations emphasise similarities across space.

Essentially, a global model indicates an average effect over a region while the local model accounts for spatial effects. For example, in some urban areas houses built in earlier times offer unusual character and quality and are more highly sought after than newer houses. At other locations, similar houses may have been built to lower standards resulting in substantially lower prices than new houses. In this case, estimates of the average age of such housing across the metropolitan area may suggest little impact on housing prices, while at the district level the effect might be significant. Therefore, by taking into account spatial variation or non-stationarity in the regression parameters the local model may improve our understanding of house price predictors.

2.1.7.2 Non-stationarity

The notion of non-stationarity is a fundamental assumption of local analytical processes. Non-stationarity means the behaviour of observations are subject to the circumstances that prevail at a location. In practice, this means the measurement of a relationship may differ according to the city or country where estimates are made. Essentially, if the process investigated (for example, house prices) is not constant over space it will not be sufficiently explained by a global model.

There are several reasons why measurements of relationships tend to vary over space. First, sampling variation may occur due to different samples used in the data set. This variation is common and often unrelated to the underlying spatial process, but it becomes important if there are substantive reasons for spatial non-stationarity. Second, spatial non-stationarity in relationships may be due to spatial variations in community attitudes, preferences or different administrative, political or other contextual matters (Agnew 1996). Third, the model used to define the relationships may be misspecified and unrelated to reality, or relevant variables omitted from the model, or the model suffers from an inappropriate functional form. In this situation, mapping local statistics becomes a useful tool to understand the nature of model suitability. For example, the spatial pattern of the relationship measured may provide important evidence regarding missing but otherwise relevant attributes and indicate additional variables that might improve the model's accuracy. Ultimately, the goal is to specify a model where spatial non-stationarity is not only identified but also explained. In this case, local modelling becomes an important diagnostic tool used to enhance the performance of the global model.

2.1.7.3 The foundations of spatial dependency measurement

Spatial dependency is defined as the extent to which the value of an attribute is dependent on the values of nearby attributes. Processes for measuring univariate statistical spatial dependency have been available for a number of decades (Cliff & Ord 1972; Haining 1979), although it was not until recently that these methods achieved general acceptance. An important development in this respect is the work of Getis and Ord (1992) who developed a global approach to spatial association, a form of spatially moving averages, that measures the way values of attributes cluster over space. The benefit of this analytical process is demonstrated in the authors' empirical findings that reveal several significant local clusters relating to sudden infant death syndrome, which were not evident in global statistical modelling.

A later development of the local statistic measurement for spatial dependency is known as Moran's I (Anselin 1995). Moran's I measures spatial distribution concentration. If attributes with high values or low values are frequently located close to other high or low valued attributes the data are described as exhibiting positive spatial autocorrelation. Conversely, if the data pattern is such that high and low values are commonly located near each other they are described as having negative spatial autocorrelation.

Various attempts have been made to develop localised models using traditionally global multivariate techniques particularly in the form of regression analysis. First, the spatial expansion method (Casetti 1972; 1997), which allows regression parameter estimates to vary locally as a function of other attributes. Second, is the spatially adaptive filtering method (Trigg & Leach 1967; Widrow & Hoff 1960). This is a regression modelling technique particularly applicable to multivariate time series analysis. This tool is essentially a ‘predictor corrector’ and is used to compensate for the drift of parameters over time. Spatially adaptive filtering is very much an iterative process where B_{t-1} is updated in relation to its nearest temporal neighbour at time t. Third, is multilevel modelling (Duncan & Jones 2000; Goldstein 1987; Jones 1991). These models combine the individual micro-level, or disaggregate behaviour, with the macro-level representing contextual variations in behaviour.

There are a number of difficulties associated with each of the above-mentioned models. In some cases, the complexity of measured trends is dependent on the complexity of the spatial expansion equation, which may obscure some important local variations. In other cases, there is heavy reliance on priori definition or where model estimates are not truly reflected by local statistics. In addition, the spatial regression models amongst those cited above are characteristically ‘mixed’ models. That is, while they recognise existence of local relationships between data, these relationships are generally measured with a global autocorrelation statistic and the model output provided in terms of global parameters. A solution to these issues, offered by Brunsdon, Fotheringham and Charlton (1998), is the application of GWR to a spatially autoregressive model. In this case, the model output provides a local set of parameters that includes locally varying autocorrelation coefficients. The outcome is a simpler, more effective way to derive a local measure of spatial autocorrelation.

2.1.7.4 The mechanics of GWR

Similar to regression analysis, GWR involves multivariate data sets. A major advantage of this technique is that it retains a traditional regression framework while explicitly incorporating local spatial relationships. The mechanics of GWR are described as follows.

The general global regression model is defined as:

$$Y_i = \beta_0 + \sum_k \beta_k x_{ik} + e_i \qquad (2.13)$$

where:

(u_i, v_i) are coordinates of the ith point in space and $\beta_k(u_i, v_i)$ is the realisation of the continuous function $\beta_k(u_i, v_i)$ at point i. GWR extends this framework by including local rather than global parameters to be estimated, and the model can be written as:

$$Y_i = \beta_0\,(u_i, v_i) + \sum_k \beta_k\,(u_i, v_i) x_{ik} + e_i \qquad (2.14)$$

This means there is a continuous surface of parameter values and measurements that can be taken at various points on the surface area to assess spatial variability. The calibration of the model assumes that observations near location *i* have more of an influence on the estimation of $\beta_k(u_i, v_i)$ than observations farther from i. Hence, the weighted least squares provide the basis for understanding the implicit relationship between location *i* and observations in its surrounding area.

The technique takes into account spatial correlations by accounting for coordinates in parameter estimates and also by considering geographical locations in the calculation of the intercept values. Du and Mulley (2012) describe the estimation process as a 'trade-off between efficiency and bias in the estimators with a weighting process using spatial kernels which capture the data points to be regressed by moving the regression point across the region' (Du & Mulley 2012, p. 51). The GWR modelling technique allows a process of adaptive spatial kernels, which means the bandwidth is narrowed if the data are dense and widened when the data are sparse.

Goodness of fit in GWR modelling is primarily assessed by an Akaike Information Criterion (AIC) system, which explicitly accounts for the complexity of the model. In general, if the AIC, which assesses the performance of the local and global model, shows a difference of more than 3 then the models are statistically significantly different and the model with the lower AIC suggests a better fit. When adaptive kernels are used in the estimation process, the GWR software automatically chooses bandwidths to minimise the AIC.

This study employs GWR4 software (version 4.0.72) to undertake the GWR calibrations described in Stage 1 research. This most recent version offers some important advantages over earlier GWR releases. In particular, it allows the use of a semi-parametric form incorporating both geographically varying and fixed explanatory variables. Priori understanding of variables that are likely fixed and those that vary over space may determine how the model is calibrated. Alternatively, GWR4 has two 'fitting techniques' to test the suitability of a semi-parametric model. First, the GtoF (from Geographically Varying to Fixed) procedure uses a process similar to stepwise regression to find the optimal combination of varying and fixed explanatory variables. Second, FtoG (Fixed to Geographically Varying) is the reverse procedure where the base case is a global model with entirely fixed parameters and the independent variables are each tested as variable. AIC uses both processes for choosing the optimal model. The major benefit of a semi-parametric approach is the potential to deliver a more conceptually satisfactory model.

2.1.7.5 The value of GWR for the present research

The traditional method used to investigate anomalies in a spatial model is to map the residuals and examine evidence of a non-random distribution. In the global model, clusters of high positive and negative residuals indicate a problem with the model. However, this evidence does not identify which parameters in the model are linked to spatial non-stationarity. Solving the problem requires local parameter estimation, which is traditionally addressed by reducing the size of the areas under study. This assumes the process being modelled is constant within each sub district. In fact, this study purposely includes discrete sub district intervals as a means of simplifying the analytical procedure. In this case, GWR provides an alternative perspective to identify potential non-stationarity unrelated to the location of statistical boundaries.

The value of GWR for the present research is its ability to reveal patterns in the data and the processes underlying them. In the first stage of this study, it is used to examine some of the unexplained variance produced by the HPM. For example, the general expectation is that property values decline as distance from transit access increases. If results are as expected the GWR model will identify how representative this conclusion is and whether there are exceptions implied by the global average. If there are intrinsic taste variations across the study area, that mean some types of housing are more highly valued in some areas compared with others, then this may qualify the findings of the HPM, which assumes these relationships are constant.

GWR also adds a level of modelling sophistication by allowing visual examination of the relationship between independent and dependent variables. Spatially limited data use GIS, which means local statistics may be mapped. This provides an opportunity to examine the intricate patterns that emerge from local estimates. In doing so, GWR reveals the interpolation of values that are not included in the data set and help detect spatial non-stationarity. Hence, GWR offers the ability to analyse multi-dimensional aspects of the rail access/property value relationship.

2.1.8 Summary

This section summarizes the findings of theoretical observations and empirical evidence relating to the determinants of property value and the effect of accessibility to rail transit systems on these values. In general, the studies reviewed show property values respond positively to rail transit accessibility. However, there is considerable variability in the findings and occasional negative results also appear in the literature.

The studies presented in this literature review have important implications for development of a suitable methodological process for Stage 1 of the present research. These studies indicate that in order to isolate transit induced property proximity premiums it is necessary to examine property prices at the disaggregate level. In this regard, it is of utmost importance that the analysis includes property physical attributes, accessibility and neighbourhood features, which are shown to have a highly significant influence on property values. In addition, the study should be cognizant of, and in some cases account for, the implications of factors that moderate rail infrastructure value. These factors relate to spatial heterogeneity, geo-cultural differences, CBD connectivity, motorway access, distance to the rail station, the effect of *place*, demographic characteristics, type of land use, type of rail investment, the effect of technology and the choice of methodology.

The literature identifies two common approaches for isolating the impact of rail accessibility on property values, both using the HPM. The first process described in this review involves estimating the difference in property values before and after an event affecting rail services at an impact compared with a control location. Choosing impact and control locations that are economically stable, apart from changes to rail services in the impact area, enables the researcher to isolate the effect of rail investment on property values without the need to account for other locational attributes. However, there are several difficulties with this approach. First, it requires an event relating to the introduction of new rail infrastructure to present itself in order that the researcher may gauge its effect. Second, it requires the availability of suitable control locations. Third, there is an issue concerning the detection of and accounting for shocks that mimic the effect of rail induced property uplift during the study period. Finally, pre/post studies typically allow insufficient time to fully encompass changes due to new rail infrastructure. In reality, the uptake of new rail service is slow and its value to travellers is realized over time.

An alternative method of analysis, and more suitable for the present study, is the separation of effects. In this case, estimations involve isolating the effect of rail accessibility on property prices at a given point in time. Hence, the availability of suitable data for this exercise is not dependent on an event relating to the introduction of new rail infrastructure. For mature rail systems, this means a study of rail transit reveals consumer attitudes to an amenity that has been fully embraced by the community. Therefore, the observations reflect the utility that consumers derive from this transport mode at a point in time determined by the researcher. The challenge here is to identify and account for other influences of *place* that generate a proximity premium apart from rail accessibility. This means taking into consideration commercial and other activities at rail locations that also act as attractors.

The present research aims to address three major issues that limit previous studies in their ability to efficiently estimate rail induced property values. First, these studies typically focus on entire metropolitan districts or corridor lines. In contrast, this study goes beyond this limitation and examines individual rail stations providing greater opportunities to assess the effects of transit in more detail. Second, no known studies have considered the value of rail accessibility regarding the effects of the surrounding *place*. This study will account for the extent and variety of activity associated with rail transit locations that can influence the size of proximity premiums. Finally, previous studies report the average effect of rail accessibility across a region. This study will highlight evidence of non-conformity at the sub-region level and, in doing so, enhance the integrity and usefulness of reported results.

2.2 Urban mobility and residential sorting

The provision of public amenities, such as rail transit, is often linked to neighbourhood ascent and with it the processes of displacement and segregation. If this is true, then these processes are likely to leave an identifiable pattern of residential sorting at treated sites reflecting differences in households' accessibility to those amenities. This section examines how these processes might occur and how they are likely to manifest in terms of local demographic characteristics. It begins with an investigation of the broader theory surrounding people movement, followed by a review of techniques used to measure residential sorting and concludes with a review of extant literature pertaining specifically to the effects of rail infrastructure on neighbourhood demographics.

It is important to note, at this stage, that the distribution of households across neighbourhoods occurs through a complex and multidimensional process that involves more than simply considerations of access to public amenities. When choosing a residential location, home-seekers must make trade-offs regarding available housing features and local community attributes (Bayer, McMillan & Rueben 2004). The sorting of population subgroups into distinct areas may indicate heterogeneous tastes or similar community political interests. It may also reflect income stratification within housing markets, with different groups making different trade-offs between convenient locations and lower residential prices. Alternatively, sorting may ensue from differences in residential tenure preference, or simply if groups prefer to live nearby people who are similar to themselves, or separate from people who are different (Maré et al. 2012). In all cases, it is the commonality of interests or constraints in these circumstances that potentially lead to some form of residential segregation.

Residential sorting is facilitated by population mobility, which is generally found to be a common phenomenon. Decisions to remain in a neighbourhood or move to another are both numerous and complex. The factors that influence decisions concerning questions such as why some residents relocate; why new residents are motivated to fill the void and why others remain uninfluenced by a change in circumstances, are not fully developed in the literature. As with many social issues of this kind attempts to explicate the relationship between community conditions and household location decisions is complicated by the multiplicity of circumstances involved in the decision-making process and complexity of multi-dimensional considerations. For example, decisions to relocate may be due in part or entirely to consumer life-cycle or status changes, socialization processes, land-use changes, or federal, state or local government programs. Indeed, to fully appreciate the myriad factors involved in such investigation invokes the need for a broader cross-discipline expertise summoning the fields of self-selection and policy planning (Mokhtarian & Cao 2008) and contributions from sociology, geography, demography and psychology (Shumaker & Stokols 1982). Unfortunately, little confluence of ideas has thus far taken place to address the needs of urban migration researchers. With this in mind, the following discussion examines the current state of theoretical knowledge relating to residential sorting and the role of population mobility in this process.

2.2.1.1 Theoretical foundations

Models that explain the effects of spatial interaction and intra-urban migration generally draw on the principles of physics and the social sciences and typically consider movements at a macro level. For example, Ravenstein (1885), Reilly (1929) and Young (1924) described the effects of urban spatial interaction and migration as analogous to Newton's law of universal gravitation. These authors assume population migration between two entities depends on their respective size and mutual distance.

Ravenstein (1885) proposed various 'laws of migration', the most important of which are discussed here. The first concerns the relationship between migration and distance which posits that migrants generally proceed only short distances and that the centre of absorption tends to grow less as the distance from that centre increases. However, migrants who choose to proceed long distances typically gravitate to larger centres of commerce and industry. The second states that migration occurs in stages. This law refers to a universal shifting or displacement of population, which produces 'currents of migration'. It involves the movement of inhabitants to towns that have growth potential from regions immediately surrounding the towns, while the void left in nearby rural areas is subsequently filled by migrants from more remote districts. This process continues until the attraction of growth cities extends its influence to all regions in the geo-political realm. The third law suggests that urban and rural residents have different propensities to migrate. That is, town inhabitants are less likely to migrate than those from rural districts. Fourth, technology promotes migration. In this regard, Ravenstein refers to both the availability of 'locomotion' and the development of manufactures and commerce that provide momentum and motivation for increased of migration. Finally, Ravenstein highlights the dominance of the economic motive:

> Bad or oppressive laws, heavy taxation, an unattractive climate, uncongenial social surroundings, and even compulsion (slave trade, transportation), all have produced and are still producing currents of migration, but none of these currents can compare in volume with that which arises from the desire inherent in most men to 'better' themselves in material respects. (Ravenstein 1885, p. 286)

In the century following Ravenstein's work many empirical studies appeared but few additional theoretical generalizations advanced. A vast number of studies have been undertaken concerning the relationship between migration and age, sex, race, distance, education, the labour force and so forth. These focus largely on the characteristics of migrants, but with little reference to the magnitude of flow or the consequent patterns of settlement. Again, these contributions provide macro level theoretical and conceptual analysis. The following sections explore some of the more prominent theories relating to the location decision and residential sorting.

2.2.1.2 Concentric zone theories

Burgess (1967) adapts von Thünen's concentric zone model of land value to accommodate residential population patterns. Burgess' model represents the 'Chicago school' of thought, which suggests the intimations of concentric tendency are evident in US city planning policies, zoning and regional surveys. This typically conforms to a pattern depicted in Figure 2.2, which has the CBD (the 'Loop') at the centre, followed by transitioning zones comprising business and light industrial, commercial offices and then worker housing. Beyond this zone is residential housing comprising 'high-class apartment buildings or exclusive "restricted" districts of single-family dwellings.' Farther out and 'beyond city limits is the commuters zone – suburban areas - within a thirty – to sixty minute ride of the central business district' (Burgess 1967).

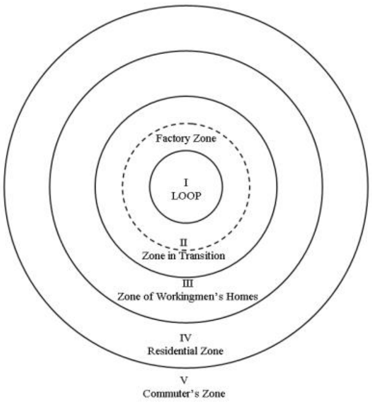

Figure 2.2 Concentric Model
(Burgess 1967)

The concentric zone approach to residential sorting continues to be widely adopted in the process of contemporary policy formulation and in academic research agendas. This is understandable given the predominant source of the literature combined with the fact that around half of the metropolitan areas in the U.S. conform to a concentric model similar to that suggested by Burgess (Dwyer 2010). However, the model has significant weaknesses and limitations. First, Burgess recognized that the processes of urban metabolism undermine the simplistic pattern of concentricity. The emergence of sub-business centres as 'satellite loops' represents the telescoping of several local communities into a larger economic unit. This is the process of reorganization into a 'centralized decentralized system' of local communities coalescing into commercial hubs that are 'visibly or invisibly' dominated by the central business district (Burgess 1967, p. 341). The simplistic assumption of monocentricity means the implications of complex land use diversity and spatial interactions are ignored in the Burgess model. In reality, the concept of land valuation is complicated by the dynamics associated with diverse land use patterns in urban environments. With the growing relevance of the urban polycentric spatial configuration, cities commonly appear as a patchwork of functional regions, which leads to multiple nuclei (Harris & Ullman 1945) each with their own spheres of influence.

Second, some observations that compare larger and more densely populated cities and smaller metropolitan regions further challenge the conceptualization of sorting determined by concentric forces. For example, Coulton et al. (1996) show that some larger urban centres with a high degree of inequality indicate a greater tendency to concentric determination compared with those where there is greater convergence of upper income groups at the urban core. Furthermore, they suggest that cities of this type often display far less predictability in their pattern of demographic concentration.

Finally, suburban areas enhanced by a greater level of public amenity, nearby employment opportunities and transport accessibility; the influence of natural aesthetic appeal such as water frontage and historical interest; or the relative degree to which communities resist change, each act to undermine the emergence of concentric urban development. Indeed, the concentric zone theory is very much a deterministic model, which tends to naturalize the sorting process and mask broader dynamic forces. Consequently, public institutions remain notably absent from concentric zone theory as do other natural city features that influence neighbourhood change. Later research has addressed some of these weaknesses by denaturalizing the market mechanism and embedding other 'macro' and 'meso-scale' processes in the study of neighbourhood transition (Goetz 2013; Jargowsky 1997).[3]

2.2.1.3 Los Angeles School of Urbanism

The Los Angeles School of urbanism refers to a group of scholars who emerged in the 1980s to investigate a new urban phenomenon reflected in the Los Angeles city region. These scholars realized that rather than conforming to accepted theory the city displayed a new kind of urban development in the form of 'postmodern urbanism'. From this point it became apparent that lessons from the Los Angeles experience could provide value to a far broader set of scholars beyond that particular city. Dear and Dahmann (2008) write,

> [To] put it succinctly, LA is simply one of the best currently available counterfactuals to conventional urban theory and practice, and as such, it is a valuable foundation for excavating the future of cities everywhere. (Dear & Dahmann 2008, p. 3)

The Los Angeles School of urbanism challenges the proposition that industrial Chicago typifies the modern city. Burgess, McKenzie and Wirth's (1925) model, with its core-to-hinterland causality and concentric rings of diminishing density and composition, has been replaced by a process where fragmentation and polycentricism are the dominant urban drivers. The Los Angeles School argues that there are many urban cores, in the new paradigm. Independent suburban hubs arise with no allegiance to the city centre, and the concept of suburbanization, long considered the peripheral accretion emanating from the urban core, no longer exists. Indeed, the Los Angeles School of urbanism so radically alters the traditional view of urban dynamics as to question into the whole concept of a city (Dear & Flusty 1998).

The direction of scholarly contributions that espouses the principles of the Los Angeles School of urbanism manifests itself in a number of ways. Kearsley (1983) sought to update Burgess's model by considering contemporary urban processes, such as declination of the inner city, gentrification, and decentralization. Some authors believe the modern paradigm is far more consistent with a 'quartered city' model comprising exclusionary suburbs, ethnic enclaves, suburbs with mixed demographic profiles and gentrified areas (Marcuse 1989). Others point to the development of transport infrastructure and the advance of information technology as reasons why cities are no longer organized into clear zones or sectors (Wei & Knox 2015).

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[3] Further discussion regarding these developments can be found in Section 2.2.1.5.

The spatial structure of cities that undergo suburbanization of employment opportunities, and take a more dispersed and polycentric urban form, have been characterized as 'urban realms' (Knox 2008; Lang & Knox 2009); or disjointed and indefinitely decentralized 'galactic metropolises' (Lewis 1983); or 'edgeless cities' (Lang 2003); and products of various multiple, differentiated employment centres at suburban hubs (Anas, Arnott & Small 1998; Coffey & Shearmur 2001). Recently, Lang and Nelson (2011) proposed the notion of a super multi-metropolis with strong economic urban regional interdependency.

It is interesting to see how socio-economic sorting has played out over time. A number of empirical studies have investigated US metropolitan socio-economic patterns (Hanlon, Vicino & Short 2006; Lang & Nelson 2011; Lucy & Phillips 2001). Some important conclusions are that there has been a slow decline in racial segregation; class segregation amongst minorities has grown over time (Jargowsky 1997); and the affluent and poor are more likely to live in separate communities far from each other (Marcuse 1989). It is also worthy to note that, in the USA for example, the structure of class segregation in cities of the historically industrial northeast and mid-west is more likely to follow the concentric model, while the west and south are less likely to manifest this form of segregation (Dwyer 2010). This suggests cities that developed in an age of downtown manufacturing are more likely to exhibit a concentric pattern than those cities dominated by new-economy industries.

Although there has been significant progress in understanding demographic change across metropolitan areas, most existing studies tend to focus on socio-economic patterns without considering the spatial pattern of transformation (Jargowsky 2003; Kneebone & Berube 2008; Mikelbank 2004; Short, Hanlon & Vicino 2007; Vicino 2008). Wei and Knox (2015) rightly suggest that 'the relationship between concomitant changes in socio-economic profiles and changing metropolitan spatial structure remains unclear' (Wei & Knox 2015, p. 52). Exploring the grass roots or neighbourhood level of metropolitan structure reveals a better understanding of these social ecologies.

2.2.1.4 Theories of social equilibrium

Coinciding with the development of concentric zone theory regarding residential sorting, theorists considered other mechanisms that determine the specific character of neighbourhoods and the phenomenon concerning economic segmentation (Park 1915; Wirth 1938). Park (1915) explains:

> Physical geography, natural advantages, and the means of transportation determine in advance the general outlines of the urban plan. As the city increases in population, the subtler influences of sympathy, rivalry, and economic necessity tend to control the distribution of population.

> Business and manufacturing seek advantageous locations and draw around them a certain portion of the population. There spring up fashionable residence quarters from which the poorer classes are excluded because of the increased value of the land. Then there grow up slums, which are inhabited by great numbers of the poorer classes who are unable to defend themselves from association with the derelict and vicious. In the course of time every section and quarter of the city takes on something of the character and qualities of its inhabitants. Each separate part of the city is inevitably stained with the peculiar sentiment of its population. The effect of this is to convert what was at first a mere geographical expression into a neighbourhood, that is to say, a locality with sentiments traditions and a history of its own. (Park 1915, p. 579)

These ideas, concerning urban morphology and neighbourhood change, suggest a model where neighbourhoods are considered closed ecosystems and demographic change tends towards a state of social equilibrium. Incoming residents, differentiated by class and/or race, lead to disequilibrium and subsequent demand for space forces out less dominant groups. The remaining groups establish a new social equilibrium which naturally arrange in-comers according to their demographic features (Park 1915). This explains the variety of neighbourhoods observed in urban systems.

Like other related concepts at this time, the theories of social equilibrium are based on a deterministic ecological model. Again, this theory naturalizes neighbourhood transition and ignores broader dynamic forces. As a result, public policy, investment decisions and other exogenous factors are not considered in the early analysis of the processes involved in neighbourhood formation.

More recently a few studies have introduced de-naturalization of the distribution phenomena and incorporated other macro processes (Goetz 2013). This shift in the theoretical focus is a product of contemporary circumstances and the elevation of social justice issues. The question of policy, individual decision making and the process of urban morphology becomes an important issue in relation to the geography of opportunity (Briggs 2005). Scholars who adopt this perspective argue that spatial relationships exist between residential opportunities and social mobility (Ellen & Turner 1997; Galster 2012; Jencks & Mayer 1990; Sampson, Morenoff & Gannon-Rowley 2002; Sharkey 2013). These scholars are primarily concerned with the role of public policy in arranging spatial distributions of resources throughout the metropolitan area. An extension of this is an emerging interest in the effect of investment in public amenities regarding the decisions that lead to residential sorting.

2.2.1.5 Demand-side and supply-side theories

This section discusses the processes at work that influence household location. Scholars argue that either the macro-forces of capital accumulation or the micro-sociological processes relating to individual preferences drive the location decision. The debate generally involves two different perspectives relating to either the flow of capital or the flow of people to neighbourhoods. The analysis to emerge from this debate focuses on either the production/supply-side or consumption/demand-side catalysts. The flow of capital focuses on profit seeking and the influence of broader economic forces that make city areas profitable for in-mover. The flow of people, on the other hand, refers to the process by which individuals are drawn by cultural and aesthetic preferences (Zuk et al. 2015).

Flow of capital

Recently, growing emphasis on economic growth through more effective use of urban strategic assets has focused attention on catalysts and their effect on neighbourhood productivity and demographic structures. Smith's (1979) production or supply-side theory of demographic transformation, widely cited and accepted in the economic literature relating to gentrification, views city administration as part of the overall political economy where the objective is to expand asset inventory through urban development programs. Smith's theory argues that macro-forces of capital accumulation drive neighbourhood transformation through the flow of capital and the movement of profit-seeking individuals. This suggests neighbourhood change is in fact the spatial manifestation of shifting capital flows.

Smith questions the consumer sovereignty hypotheses that dominate explanations of neighbourhood transition particularly regarding gentrification. Smith argues that demographic transformation is an expected outcome of unhampered land and housing markets. He cites the economic depreciation of capital invested in nineteenth century inner-city neighbourhoods and the simultaneous rise in potential ground rent levels, which gives rise to the possibility of profitable redevelopment. This means that demographic restructure can be influenced by profit motivation rather than simply interest of social cohesion. Smith says:

> Although the very apparent social characteristics of deteriorated neighborhoods would discourage redevelopment, the hidden economic characteristics may well be favorable. Whether gentrification is a fundamental restructuring of urban space depends not on where new inhabitants come from but on how much productive capital returns to the area from the suburbs. (Smith 1979, p. 538)

As outer suburb new housing construction costs rise and the distance to the city centre increases, the rehabilitation of inner-city structures becomes more viable economically for outer urban dwellers. Structurally sound properties can be purchased and rehabilitated for less than the cost of comparable outer zone new housing. In addition, incomers benefit from improved proximity to work saving the cost of petrol for private cars and public transportation fares. Smith suggests that, contrary to conventional wisdom, gentrification demonstrates that middle and upper-class households are capable of intensive land use and are not inflexible when it comes to locational choice. Indeed, the process of gentrification by these groups is closely aligned with reinvestment.

Those that initially benefit from relocating capital are members of the community targeted for investment. If targeted neighbourhoods continue to attract productive capital it may lead to a fundamental restructuring of the area. In a continuation of the filtering process, out-movers theoretically inherit the outer declining suburbs and are trapped in areas that are less blessed with public infrastructure. This process tends to be cyclical. However, the longevity and fixity of such investments, means new waves of investments are likely to be associated with shocks related to public or private accumulation decisions (Harvey 1978). In this context, the resurrection of the neighbourhood represents the leading edge of urban renaissance and restructuring of space. This process is accomplished according to the needs of capital and can be accompanied by a cultural change to neighbourhood environments. The old order is replaced by a new social, economic and cultural landscape to reflect the demographic characteristics of new residents. Smith suggests these concepts are neither new nor mutually exclusive. Indeed, '[T]hey are often invoked jointly and share in one vital respect a common perspective - an emphasis on consumer preference and the constraints within which these preferences are implemented' (Smith 1979, p. 539).

This theme is shared with neoclassical residential land use theory presented by Alonso (1964), Mills (1972) and Muth (1969), which suggests that the process of suburbanization reflects the preference for space and the increased ability to pay for it due to savings in transport costs. Smith explains that gentrification is similarly the result of a change of preferences and the constraints determining which preferences can and will be implemented.

Smith's (1979) argument effectively de-naturalises deterministic theory and suggests urban transformation should be viewed not as a movement of people but as a relocation of capital investment. However, the problem with this strict supply-side approach is that it focuses solely on production side interests, for example, developers, financiers, government bodies and real estate agents that form the larger political economy relating to neighbourhood investment. This focus obscures individual ascription in favour of a macro view of neighbourhood transformation, which is simply a function of the capitalist economy.

Flow of people

Concepts relating to the flow of people are grounded in 'consumer-driven demand-side principles' (Zuk et al. 2015). Rather than following the flow of capital, in-movers and out-movers focus on aesthetic and lifestyle preferences (Caulfield 1994; Ley 1996; Zukin 1989), or respond to the shifting labour market (Hamnett 2003; Rose 1984; Zukin 1987). The former group of authors examine motivations to move from outer to inner suburbs, such as political identification or housing choices. The latter consider the links between employment opportunities and the location choice of individual home-seekers.

Some groups show a preference to congregate in areas that predominantly feature people of similar background (Freeman 2011; Hyra 2008; Moore 2009). This concept ties the neighbourhood processes to larger structural issues of residential concentration (Zuk et al. 2015). For example, home-seekers may identify with a particular set of cultural practices and aesthetics that link to their racial background (Freeman 2011). In this case, the dominant characteristics of some cultural enclaves are often less inviting to those of different cultures leading to the impression of exclusivity. Other residential sorting may evolve from income inequality leading to displacement and segregation. Alternatively,

> …[t]he sorting of population subgroups into distinct areas may reflect heterogeneous tastes, with segregation supporting the provision of local public goods or proximity to amenities valued highly by the subgroup. (Maré et al. 2012)

The concepts of public choice and income inequality are briefly examined in the following sub-sections. This is followed by a review of modern mobility theory that helps explain the issues of displacement, segregation and their relationship with public investment.

Sorting by public choice

A relatively new branch of residential sorting theory involves community level public choice behaviour. Public choice demand side theory has its foundations in offerings by Musgrave (1939) and Samuelson (1954) and the seminal work of Tiebout (1956). Tiebout suggests that economic segregation is the result of consumers' preferences for different baskets of public goods at different local jurisdictions, which attract residents of equivalent economic means (Peterson 1981). The premise of the argument is that, given individuals apply different valuations to the provision of public amenities and have varying ability to pay for those services, they will move to locations that maximize their personal utility. This implies that, through individuals' choice processes, home-seekers will determine an equilibrium position whereby community character and the services offered aligns with the preferences of local residents. This leads to sorting into optimum communities with common preference systems and a similar ability to pay for the basic cost of residency.

Tiebout's (1956) argument is underlined by the following assumptions: first, consumer-voters are fully mobile and able to locate to any community where their preference patterns are best satisfied. Second, consumer-voters are assumed to possess a full knowledge of local government differences in relation to revenue and expenditure patterns and react to these differences. Third, there are a sufficiently large number of communities to accommodate the variability of consumer-voters' preferences. Fourth, there are unrestricted employment opportunities. Fifth, the public services provided by government exhibit no external economies or diseconomies between communities. Sixth, there is an optimal population size for every community. This size is defined as the number of residents for which a bundle of services can be produced at the lowest average cost. Finally, communities below the optimum size tend to attract new residents with lower average costs, while those communities that have reached capacity do the opposite.

Given the assumptions of the Tiebout model residents are free to pursue the type of public amenity they desire, subject to financial constraints. Communities found to be at optimum size may invoke zoning laws and regulations to keep the population stable. In addition, realty prices help to contain population expansion. When a community is in equilibrium, there will be no movement from or to that location. If equilibrium does not exist there will be a proportion of consumer-voters who are discontented with the pattern of their community and another subset that are satisfied. In these circumstances, Tiebout's mobility assumptions predict movement of households to optimize communities. Hence, consumer-voters sort into communities that best satisfy their preference pattern.

Teibout suggests a financial shock incurred by a community, due to an event, has the potential to induce residential sorting. If this event leads to a premium for occupancy, then residents who are indifferent to local amenities will be forced to consider their position in terms of their residential location. The question for residents is whether the saving of the outlay is worth the cost of relocating to a community with no premium. Ceteris paribus, the higher cost involved in relocation the less optimal the outlay of resources.

The concept that home-seekers choose their location by selecting neighbourhoods offering bundles of public amenities that match their optimal mix of services, remains relevant today. Indeed, Tiebout 'sorting' accounts for the variation of public amenities observed in different neighbourhoods, which is largely a result of the heterogeneity found in household preferences and incomes. The sorting process leads to communities that are, more or less, homogeneous. Therefore, 'in urban areas households in the same neighbourhoods have similar demands for services, comparable abilities to pay for these analogous aspirations for local economic and physical environments' (Islam 2012, p. 443).

The Tiebout theory of sorting is important to this study because it helps to explain the relationship between the movement of people and individual preference systems. The question whether similarity of preferences is associated with similarity of demographic characteristics is very much at the heart of the present research. Yet Tiebout does not provide a comprehensive solution to the question of why sorting occurs. Today the singular interaction of consumer preference and public administrative response is considered restrictive. We now know that neighbourhood economic segregation is strongly influenced by income inequality, which allows some households to pursue their locational preferences (Reardon & Bischoff 2011).

Income inequality

Some geographical areas are more productive than others, which can lead to income inequality and concentrations of groups with distinctive characteristics. A recent article by Ganong and Shoag (2017) argues that the prohibitive cost of living in areas of greatest economic opportunities can force low income earners to settle in areas of inferior opportunity. The authors demonstrate this idea by explaining the migration patterns of two occupations, lawyers and janitors, in New York. Here, the nominal premium for living in the metropolitan area is large for both occupations. For in-moving lawyers, income net of housing costs is 79%, while for janitors it is 48%. This condition is exacerbated by low housing elasticity and the fact that income differences are, to some extent, capitalized into housing prices. While it is worth the move to New York by lawyers, the high cost of house prices offset the nominal wage gains for janitors, given alternatives elsewhere. The result is that high-skill workers move to high-income places and low-skill workers leave. The authors call this 'skill sorting', and it is a phenomenon that can be generalized to all low and high skilled workers.

Again, this has implications for the present research. It demonstrates that localities with a higher productive potential generate both higher property prices and residential sorting. In extreme cases, similar to that illustrated by the New York example, this leads to the possibility of a community defined by its high income, and highly skilled residents with distinctive educational and occupational characteristics. However, this is not just an issue for New York. In less obvious cases, where local property price premiums are nevertheless present, in-movers and out-movers must similarly assess the impact of housing costs as a proportion of income. Therefore, income, profession and potentially education can be significant factors in determining locational attainment.

2.2.1.6 Modern mobility theory

Modern mobility theory builds on the concept of the individual perspective and assumes rational cost-benefit analysis underlies the relocation decision-making process. This theory posits that mobility is the result of an investment decision whereby expected benefits or rewards exceed the losses associated with a move from the place of origin. This economic model assumes utility can be assigned to the place of origin and alternative places such that an informed comparison of current and expected gains or losses can be made, and location decisions are determined by decision maker's 'action space' and/or opportunity awareness (Lee 1966).

In a branch of this argument, some scholars contend that mobility occurs in response to individual stress. If the environment does not meet expectations in fulfilling a resident's needs it is said to have a lack of fit, or incongruity, which manifests itself in stress. When a certain level of stress is reached the resident considers relocation (Shumaker & Stokols 1982). There are various sources of incongruity, including those that evolve from changing life-cycle needs or change in social status (Rossi 1980).

However, research conducted by Speare, Goldstein and Frey (1975) throws doubt on the appropriateness of the stress threshold catalyst theory. Their study tests a mobility theory representing an elaboration of previous cost-benefit models and concludes it is not necessary to invoke stress to predict whether residents choose to move. Rather, residents have a 'threshold of dissatisfaction' at which point they consider alternatives with their current locale providing a basis for comparison. Factors that influence satisfaction include changing needs for home or neighbourhood amenities. For example, households' preference systems may shift due to a change in family size or prioritization of children's' needs. Other factors may relate to changes in evaluative standards (social mobility). Speare, Goldstein and Frey suggest that the threshold of dissatisfaction triggers a cost-benefit analysis that includes an evaluation of the current residence, the cost of alterations to the current residence (refurbishment), and the cost/benefit of relocating.

The previous discussion shows the dynamics of residential sorting involves a complex process of home-seeker decision-making influenced by both demand and supply side factors. Fundamental to the process of sorting is the displacement phenomena. The following sections examine the concept of displacement and the influence of public amenity in this process.

2.2.2 Displacement

Unfortunately, very few studies satisfactorily address the issue of displacement. Most literature relating to the phenomena is descriptive in nature and involves little in the way of hypothesis testing. Furthermore, available related empirical research concerning displacement focuses primarily on the revitalization effects of neighbourhood transition soon after investment rather than the long-term equilibrium position. Nevertheless, transformation studies are useful as they juxtapose with the findings of studies, such as this, that consider the long-term effects of public infrastructure investment.

Zuk et al. (2015) observe a growing interest, on the part of scholars and advocates, in public investments and how these investments might create a situation where some residents are forced out of, or unable to move in to, areas that suit their needs. Activists and social justice groups consistently identify displacement as the greatest issue emerging from neighbourhood transformation which follows public and private infrastructure projects. For this reason, scholars place great importance on the processes that measure, assess and predict displacement in neighbourhoods following public and private investment.

2.2.2.1 Causes of displacement

Newman and Owen’s (1982) examination of the literature dealing with neighbourhood transformation following the introduction of new infrastructure reveals a number of circumstances that give rise to residential displacement. Primary amongst these, and most relevant to this study, is the situation where investment increases demand for housing stock, which means property prices and rents rise. This increased cost will force low-income residents, with least ability to pay, to seek alternative lower cost housing. In addition, the rehabilitation of rental property conversion to higher priced owner-occupied housing may result in the relocation of resident incumbents.

Newman and Owen note that the issues surrounding displacement are on-going and have long been a part of the urban narrative. However, a growing recognition by public and private investors of the potential to capitalize on neighbourhood rehabilitation has recently increased investment activity. Studies, such as Newman and Owen’s, shows the inflow and outflow of residents, following investments, based on their ability to pay for residency can lead to changes in demographic profiles of neighbourhoods, at very least in terms of income.

2.2.2.2 The impact of displacement on demographic change

The subject of displacement and its implications receives intermittent attention from various fields of the social sciences. These studies suggest economic characteristics are most likely affected by neighbourhood investment. They show that households of considerable income and/or wealth have the flexibility to make long-term plans with choices from a broader range of options. In this way, households of means are able to 'purchase' freedom from disruptive events (Ehrlich & Duncan 1975).

Those who are most disadvantaged may have less ability to withstand the burden of higher housing costs. For example, unskilled workers with intermittent work are less likely to cope with higher living costs than skilled workers with greater employment options. This concurs with earlier theoretical observations that occupation is potentially a key factor in the process of residential sorting at transformed neighbourhoods.

Societal changes also influence residential sorting. Some proponents of demographic explanations of neighbourhood ascension are not persuaded that simply supply led economic restructuring constitutes sufficient cause to influence demographic characteristics. The argument suggests that social values adjust sufficiently to accept smaller families and two income households. Without this, most of the population would lack either the means or be otherwise unsuitable for the style of living at transformed neighbourhoods. Indeed, the interaction of social and economic factors ultimately conditions residential choices.

Many studies of neighbourhood ascent show that in-movers are largely a homogeneous group who often tend to alter residential density as they replace the existing population. On the other hand, out-movers tend to be a relatively heterogeneous group (LeGates & Hartman 2007) who are often characterized as economically vulnerable, though not always disadvantaged (Zukin 1987). The effect of a more economically viable base and greater consistency in revitalized neighbourhoods is likely to initiate a type of cultural change and with it a shift in the community's support mechanisms, adapted to the new demographic.

Freeman (2005) suggests the process by which decline and disinvestment in neighbourhoods is reversed has emerged as 'one of the most controversial issues' in the field of urban politics.

However, Freeman believes that infrastructure and public housing investment attracts middle-class residents and the process of renewal has the potential to revitalize depressed city neighbourhoods. Following extended periods of disinvestment and middle-class exodus neighbourhood transformation will be seen as a welcome development.

Many cities have experienced changes in the demographic composition of revitalized suburban locations towards more affluent and better-educated residents. For authors such as Freeman, this urban shift of the middle and professional classes, formerly confined to the outer suburbs, presents an opportunity to reverse urban degradation and to meet societal goals concerning improved urban mix. The fiscal problems, some formerly run-down urban districts face due to their higher concentration of low income households, can be ameliorated if wealthier households settle within these areas by raising taxable income, stimulating retail activity and increasing property values (Mieszkowski & Mills 1993).

Without displacement, the process of urban renewal can improve integration and therefore enhance opportunities for existing residents. For example, the growing presence of a middle class in formerly low-income neighbourhoods can lead to desegregation of communities and the local educational facilities (Lee, Spain & Umberson 1985). Also, life opportunities for indigenous residents may be enhanced if middle-income households emerge in traditionally disadvantaged neighbourhoods (Wilson 2012). In addition, existing residents of revitalized neighbourhoods may benefit if renewal brings new housing investment and stimulates retail services and cultural activities. The infusion of residents with greater political influence may also help communities to procure improved public services and employment prospects for low-income residents may be enhanced if renewed neighbourhoods lead to local job creation and employment networks enriched by incoming of new residents (Freeman 2005).

Freeman and Braconi (2004) point out that despite the potential benefits, local populations and community activists often oppose the urban neighbourhood’s renewal programs. The authors go on to explain:

> Although the rhetoric of resistance sometimes expresses class and racial resentments, the principal concern is usually that lower-income households are vulnerable to displacement resulting from redevelopment projects or rising rents. A common response is for activists to pressure local government for more affordable housing development, to organize community development corporations for that end, or to establish service programs that provide legal or financial assistance to renters who face eviction. In some cases, however, opponents have sought to block community improvement projects through political pressure or legal challenge. (Freeman & Braconi 2004, p. 39)

The threat of incumbent resident displacement from ascending neighbourhoods has become such a major concern that some community groups are reflexively opposed to public or private investment that may in fact lead to community enhancement. Increasingly apparent, concern over displacement is the primary motivating force behind opposition to such investments by community activists. Indeed, some scholars ‘look askance’ at community redevelopment on the assumption that it is automatically harmful to the indigenous residents (Hartman 1979; Smith 2005). For this reason,

> …it is imperative that social scientists and policy analysts provide better quantitative evidence of the extent and implications of displacement and of the effectiveness of strategies intended to mitigate it. (Freeman & Braconi 2004, p. 40)

To date, empirical evidence concerning displacement and the processes by which neighbourhoods putatively undergo gentrification is by no means definitive (Freeman 2005). In the absence of evidence to the contrary, neighbourhood ascent has become synonymous with displacement in the same way that racial transition is synonymous with the movement of white residents (Crowder 2000). Yet, unlike the latter type of neighbourhood change, there is little persuasive empirical evidence that reveals how neighbourhoods actually change (Freeman 2005).

2.2.2.3 The impact of displacement on commercial activity

Displacement and neighbourhood demographic change can lead to a change in commercial activity, which in turn reinforces the process of demographic change. Chapple and Jacobus (2009) note that shifting cultural preferences and purchasing power accompanying demographic transition in transformed neighbourhoods can influence the mix of local commercial activity. Also, changes in local retail amenities may instigate demographic change as it signals to prospective in-movers that a neighbourhood now appeals to a new type of resident (Brown-Saracino 2004).

Apart from retail changes in response to a new consumer base, broader structural changes to the retail landscape may emerge in transformed areas. Commercial gentrification may encourage the introduction of national retail chains, which replace small community orientated shops (Lees 2003; Zukin et al. 2009). Large chains generate their own additional customer traffic that can create a positive environment for the emergence of various other commercial services. In these cases, commercial rents tend to rise as more businesses compete to capture a higher level of local spending (Chapple & Jacobus 2009; Kennedy & Leonard 2001).

Empirical studies that examine the nature of commercial change in transformed neighbourhoods are limited but tend to convey a similar message. Bluestone, Stevenson and Williams (2008) found that areas nearby rail stations often experience heightened retail and other commercial activity due to the high level of foot traffic associated with transit accessibility. This in turn raises residential demand due to the variety of amenities offered in these areas. Chapple and Jacobus (2009) also demonstrate a distinct correlation between retail growth and revitalized neighbourhoods. Examining formerly depressed neighbourhoods, Meltzer and Schuetz (2012) found that retail accessibility improves rapidly following neighbourhood transformation. Finally, Meltzer and Ghorbani's (2017) study of changes to economic activity indicates new businesses in revitalized neighbourhoods tend to increase overall employment, while incumbent residents are likely to lose jobs. Each of these results suggests that commercial activity responds to changes in local economic circumstances.

2.2.3 Segregation

Among equity advocates there is strong concern about the potential for gentrification, displacement and segregation. Questions often raised are: How many residents with low incomes or minority race benefit from transit stations? Do wealthier, less diverse residents, lured by the proximity of transit and other amenities that accompany transit induced neighbourhood revitalization, gradually displace incumbent residents? Empirical evidence reviewed so far provides little consistency in answering these questions.

Policymakers and planners currently face a major dilemma. For example, if transit infrastructure investment inevitably leads to gentrification and displacement, then do authorities proceed with projects and accept the loss of neighbourhood diversity? Alternatively, do they reject transit projects designed to serve diverse, low-income neighbourhoods and leave those residents without transit improvements? This dissertation is based on research that is designed to explore the issues raised in these questions. It seeks to understand whether neighbourhood transition and displacement and long-term concentrated demographic patterns emerge at rail-transit locations beyond the normal metropolitan diversity. Where spatial patterns of neighbourhood concentration are found it is important to understand the underlying mechanisms that drive segregation and exclusion. This provides the basis for the development of appropriate policy tools that can be used to shape equitable neighbourhood change in both old and new transit centres.

2.2.3.1 Defining segregation

Residential segregation is largely the spatial manifestation of residential sorting. The term is generally used to describe spatial separation of minority demographic groups into distinctive communities. Massey and Denton (1988) suggest that neighbourhood segregation is a global construct that subsumes five distinct dimensions of spatial variation: evenness, exposure, clustering, centralization and concentration. The authors elaborate as follows:

Evenness is described as the degree to which the percentage of minority members within residential areas are equivalent to the proportion represented in the overall city. As evenness in city areas depart from the city norm segregation increases.

Exposure 'is the degree of potential contact between minority and majority members'. This reflects 'the extent to which groups are exposed to one another by virtue of sharing neighbourhoods in common'.

Clustering refers to arrangement of minority areas and the extent to which they adjoin one another over space. This is maximized when minority neighbourhoods coalesce to form one large, contiguous precinct and minimized when they are scattered widely over space.

Centralization is 'the degree to which minority members settled in and around the centre of an urban area, usually defined as the central business district'.

Concentration is 'the relative amount of physical space occupied by a minority group; as segregation rises, minority members are increasingly concentrated within a small, geographically compact area'.

This conceptual framework for estimating the extent of segregation is useful for evaluating demographic patterns in the present research.

2.2.3.2 Segregation studies and their limitations

In a recent review Hanson (2003) noted that articles categorized as dealing with 'segregation' accounted for over one quarter of all published articles in leading urban study journals. In Australia, as internationally, the subject focus of most segregation studies is ethnicity. However, only rarely do studies relating to segregation consider other aspects of 'dissimilarity', such as age, household family structure and other demographic characteristics, all of which similarly contribute to urban disparity. Only recently, Johnston, Forrest and Poulsen (2001) proposed a new approach to the analysis of residential segregation, which recognises the need to incorporate several population dimensions in these studies. Dunn, Kenna and Burnley (2007) similarly argue that 'segregation is a complex multi-dimensional urban process and our understandings of this complex urban phenomenon should not be limited to the examination of a single set of variables…' (Dunn, Kenna & Burnley 2007, p. 546).

Dunn, Kenna and Burnley (2007) believe that segregation only attracts policy attention if it presents itself as a real maladies. The authors suggest that:

> …matters of ethnic segregation only matter insofar as they have some identifiable impact upon subsequent settlement patterns, and more importantly, whether they are associated with uneven social and economic conditions and the broader matter of civic participation. (Dunn, Kenna & Burnley 2007, p. 547)

Indeed, segregation has long been assumed to have a negative connotation (Young 1999). It is generally seen as introducing intergenerational disadvantage for sections of community, or inversely, to protect and isolate affluence. In fact, segregation is often considered a source of serious injustice. For example, Young (1999) asserts the most important effect of segregation is that it 'produces and reinforces unjust privileges and disadvantages' (Young 1999, p. 240). In fact, there are few studies that consider the advantages for people living amongst others with similar socio-economically profiles. Also, the process of voluntary self-segregation has only recently entered the urban research agenda (Atkinson 2006; Atkinson & Flint 2004; Dowling & McGuirk 2005; Gwyther 2005; Kenna 2007; Low 2003).

This dissertation responds to the concern that the value of research dealing with segregation has been limited by its scope. The emphasis strictly on ethnicity limits the conceptual base for segregation research and therefore the contribution it can make to policy decisions that involve what is essentially a complex urban process. The present study will endeavour to broaden the conceptual reach of segregation research by investigating the sorting of multiple demographic variables in response to long-standing public investment. The intention is that policymakers, governments, business, interest groups and others are offered a more comprehensive narrative of people, places and the impact of neighbourhood enhancement.

2.2.4 Measuring the effects of neighbourhood ascent on changes in demographics

The paucity of empirical evidence concerning neighbourhood revitalization and its relationship with residential sorting is partially explained by the complexity involved in the analytical process. However, a number of studies have attempted to address the matter. This section reviews the literature that shows the effect of public investment on residential sorting. These studies are also relevant in circumstances involving changes in the public's valuation of existing local attributes.

An early attempt to estimate the general effects of neighbourhood ascent was conducted by the National Urban Coalition begun in 1976 (NUC 1978) . The goal of the study was to determine the cost, rate, scale and social implications of neighbourhood revitalization and displacement and to identify areas that required policy intervention. This research was based on interviews with a wide range of stakeholders including, city planners, real estate agents, housing specialists and neighbourhood groups in 44 cities throughout the USA.

A number of important findings emerged from the NUC US study. First, it showed that public transport patterns played an important role in the sustainability of rehabilitation activity. Second, the study revealed that neighbourhood revitalization was typically accompanied by changes in the demographic composition of these areas. Incoming residents were generally young, white, middle class, white-collar workers and appeared to replace residents who were elderly, non-white, lower class, blue collar or unemployed. Third, the study showed that homeowners substantially increased in rehabilitated areas and renters were largely displaced.

The NUC (US) study remains one of the most comprehensive investigations into the nature and extent of displacement to date. It has important implications for the present study as it highlights the fact that demographic composition is affected by neighbourhood rehabilitation associated with the provision of public transit. However, a major methodological issue is that the study is based entirely on the impressions of local observers with no reference to statistical data, which makes the results difficult to evaluate.

As an alternative approach, Goodman Jr (1978) developed a residential mobility model based on the housing consumption utility of residents. Goodman predicted that local mobility was most likely to occur among households whose housing consumption deviated from their utility maximizing expectations and whose monetary costs of moving were least. Goodman assumed that actual and optimal housing consumption was measurable by housing expenditure. The difference between actual and optimal expenditure was then translated to an index of housing stress. The theory posited that families moved to new dwellings if the perceived value, measured by increased utility derived from moving, exceeded the disutility of the current location. Goodman's model was specified as follows:

$$P(M) = f(E - E^*, S - S^*, A - A^*, L - L^*, Z) \tag{2.15}$$

where:

$P(M)$ = the probability of a family moving

E and E^* = the actual and optimal housing expenditure, respectively

S and S^* = actual and optimal size of the housing, respectively

A and A^* = actual and optimal housing qualities, respectively

L and L^* = actual and optimal location attributes, respectively

Z = vector of other local mobility determinants.

Goodman hypothesized:

$$dP(M)/d(S - S^*) > 0, for\ S - S^* > 0;$$
$$and < 0, for\ S - S^* < 0 \quad (2.16)$$

This applies to all arguments, apart from *Z*.

This means the probability of household relocation is determined by the discrepancies between actual and optimal consumption of housing, either overall or in any of the major housing characteristics. Goodman's study is significant because it was one of the first to offer a model that captures residential mobility decision-making in the context of a dynamic consumer framework. This is important because it demonstrates the process of adjusting housing consumption involves a lagged adaptation to a new equilibrium position. Other important contributions are that it views households as consumers of housing; the mobility decision is considered a function of disequilibrium in housing consumption and moving expenses; and housing is viewed as a bundle of attributes. The main difficulty of Goodman's study is the translation of theoretical concepts to operational variables. This issue means the study provides poor confirming evidence of the relationship between housing consumption disequilibrium and moving expenses, therefore impugning the model’s ability to predict mobility behaviour.

Weinberg (1977) uses a simultaneous model approach to measure intra-urban household mobility. The aim of the study is to evaluate the applicability of the workplace location dominance assumption. Weinberg’s study examines interdependency of residential and workplace mobility and its role in the household location decision-making process. The most important contributions of Weinberg’s study to the present dissertation are that it incorporates explicit microeconomic analysis of locational decisions including housing supply activities; it demonstrates that resident’s origin can affect housing choices; and it employs structural and neighbourhood household characteristics to determine the residential mobility decision.

Boehm (1981) models the relationship between expected future mobility and the current tenure choice. Boehm examines this relationship by estimating a joint logit probability model where tenure choice and expected mobility are both considered endogenous variables. The logit coefficients represent the effects of variables relating to tenure choice and expected mobility. The significance of the results for the present study is that it demonstrates the importance of residents’ age in the decision concerning tenure choice. This also acts as a proxy for expected mobility and household wealth. Hence, it recognizes the existence of a simultaneous relationship between tenure choice and expected mobility. The main deficiency of the study lies in the data sample. Respondent households are restricted to recent movers. It also excludes some inter-metropolitan movers and only those with access to information on the housing alternatives in their markets are included in the study.

Somewhat more rigorous in its attempt to analyse the process of residential search and mobility is a study provided by Weinberg, Friedman and Mayo (1981). Their research is based on housing demand equations focusing on microeconomic elements of household behaviour and incorporating housing market features. The model estimates the benefits of moving by measuring potential compensation in terms of disposable income. This allows changes in household and housing market characteristics to influence location decisions. The motivating factor is therefore the benefit derived from moving, offset by moving costs. Hence, the decision to move is based on household adjustment of housing consumption to the desired equilibrium level.

In the model presented by Weinberg, Friedman and Mayo, households move when the expected gain from changing location outweighs the costs of searching for and moving to a new residence. If there were no costs associated with searching and moving and there were no other impediments, households would automatically and immediately adjust their housing consumption in response to their changing circumstances. This suggests that renters, who typically have fewer impediments to adjust their housing consumption, are more likely to move in response to changed circumstances.

In Weinberg, Friedman and Mayo's model, the utility gain foregone by not moving is measured by the potential income compensation. Hence, if the net expected gain from moving is positive, households are likely to seek new accommodation and move. This can be expressed as follows:

$$IC_j = \widehat{IC} + E_{IJ} \tag{2.17}$$

$$TC_j = \widehat{TC} + E_{2J} \tag{2.18}$$

where:

IC_j and TC_j = the benefits and costs of household j, respectively.

$\widehat{IC}_j$ and $\widehat{TC}_j$ = the benefits and costs of moving household j, respectively.

E_{1J} and E_{2J} = the random errors.

The model for searching and moving is specified as follows:

$$P_j = Prob(IC_j > TC_j) \tag{2.19}$$

where:

P_j = the probability that household j will search and move.

Findings of the research show that the benefits accruing to low-income households are small. Furthermore, the offset of compensation through non-housing benefits at revitalized neighbourhoods means the benefits of moving are further reduced. The Weinberg, Friedman and Mayo model is a useful concept as it explains the conditions for moving by the inclusion of a monetary measure. Nevertheless, there are weaknesses due to the difficulty of estimating aggregate demand. For this reason, the Weinberg, Friedman and Mayo mobility model is at best an approximation.

A study by Kain and Apgar Jr (1985) takes a further step in modelling the mobility process. The authors examine how specific policies affect individual households and neighbourhoods in general. The object of the study is to show how revitalization projects can lead to displacement. A simulation model is used to study urban housing markets. The model selects four variables that predict moving behaviour: the age of household residents, prior tenure record, changes in employment, and changes in family size. It includes those households that intend to vacate their current dwelling units and participate in the housing market during the year. The model states that the decision to move for each household is a function of the probability that they will take into account one or more of the four variables.

The results of the study show the extent of policy induced displacement of low-income is likely to be minimal. Neighbourhoods selected for the study are low-income urban areas, which means relatively higher shares of rental properties and potentially higher mobility than would normally be expected. According to the authors, the process of neighbourhood revitalization often takes a decade or more and over this length of time newly formed households in the area represent a considerable proportion of all families participating in the housing market. Hence, the modelling indicates that long-term residents account for less than 20% of all households residing in the study area. Kain and Apger suggest that many displaced households gradually move out of upgraded neighbourhoods even without an investment program acting as a catalyst. Thus, estimates from Kain and Apger's study indicate that policy displacement affects fewer than 3% of households living in the target area.

The findings of Kain and Apger's study provide a number of important evidential backgrounds for the present dissertation. First, their study demonstrates that policy induced neighbourhood demographic change is less likely than change as a result of natural circumstances that apply to metropolitan areas generally. Second, there is no significant evidence that public policies adversely affect housing consumption of displaced or discouraged households. Finally, the study suggests the process of demographic transition in policy-affected neighbourhoods should be viewed as a long-term response.

Newman and Owen (1982) conducted a study to assess national displacement following urban revitalization in the USA. These authors used longitudinal data to estimate the extent, nature and impact of displacement. Their research focused on residents who moved out of their neighbourhood due to accommodation conditions or eviction following the sale of properties. Newman and Owens tested susceptibly to displacement using a logit regression function with four predictors: demographics, socio-economic characteristics, housing attributes and environmental factors. The authors calculated that the annual rate of displacement during the study period was 8.2% of all urban families who moved. The findings also supported the assumption that those residents who begin in a relatively disadvantaged position have greater susceptibility to adverse events. Conversely, those who are financially better off are less susceptible to displacement caused by revitalization. Finally, the authors concluded that the initial position of disadvantaged groups influenced the degree of susceptibility to 'shocks' but that displacement did not always result in severe consequences for the least well off.

The main contribution of this study to the literature is that it considers fundamental questions concerning displacement previously neglected in empirical research. These questions relate to the scale of displacement, the characteristics of those displaced and the effects of displacement. For the purpose of the present study, the results of Newman and Owen's research also provides useful background information regarding the extent of displacement and those that are most susceptible to displacement. However, the study has two important deficiencies. First, it ignores important mobility determinants such as neighbourhood conditions and local housing characteristics, which limits its contribution to understanding the relationship between local price uplift and displacement. Second, the concept tested in the study focuses on people rather than places. The lack of a contextual measure, which reveals the effect of *place*, remains an important weakness of the analysis.

A study by Atkinson (2000) was one of the first to employ disaggregated data in measuring the impact of neighbourhood ascension on displacement. The paper combines cross-sectional and longitudinal census data to measure gentrification via proxies representing changes in the number of professionals, numbers of working class, unskilled labour, unemployed, renters, non-whites, elderly and single parent households. Atkinson demonstrates a displacement effect clustered around gentrified wards. Furthermore, unlike Kain and Apgar Jr (1985), Atkinson (2000) observes a clear link between the displacement of vulnerable groups and the process of neighbourhood renewal.

Atkinson's (2000) study is important to this research as it demonstrates a significant cause and effect relationship between neighbourhood ascent and a variety of demographic factors. However, the author cautions the value of his study is limited by its attempt to capture the effects of neighbourhood change over the broader metropolitan area. To provide a deeper understanding of displacement the author acknowledges the need to consider smaller geographic parcels.

Vigdor, Massey and Rivlin (2002) seek to determine if low-status Boston households are more vulnerable in revitalized neighbourhoods compared with other locations in the metropolitan area. The authors use regression analysis to test the residential stability of gentrified areas. In this study, the change in the level of higher educational achievement defines preference-driven gentrification, and changes in owner-occupied housing values signify income-driven gentrification. Displacement is proxied as simply the outflow from neighbourhoods, which are classified as having undergone gentrification. The results of Vigdor, Massey and Rivlin's research are useful to the present study because they reveal a higher housing turnover in revitalized areas. However, they are less definitive regarding displacement. There are two main problems with the study. The first, is dealing with the counterfactual. Specifically, what is the effect on vulnerable households if revitalization had not taken place? Second, like Kain and Apgar Jr (1985), Vigdor, Massey and Rivlin include large study areas, which may conceivably smooth neighbourhood variability and therefore mask the true nature of displacement.

Freeman and Braconi's (2004) study aims to discern how neighbourhoods that are catalysed into gentrification are affected by displacement. The approach taken examines the relationship between residents in gentrifying neighbourhoods and residential mobility among disadvantaged households. The authors assume that if gentrification increases displacement, ceteris paribus, there should be evidence of higher mobility among disadvantaged households residing in ascending neighbourhoods compared to those residing elsewhere in the city. Their study compares the out-movement rates of low-income households in gentrifying New York boroughs to the corresponding rates of neighbourhoods that are not subject to gentrification.

In the Freeman and Braconi study, gentrification is based on changes in racial composition, rent, educational achievement and income. To control for the possibility that disadvantaged households differ systematically in a manner that makes them less likely to move, the authors develop a multivariate model of residential mobility based on the stages of housing consumption. The model posits that life-cycle events lead to consumption discrepancies and induce households to relocate (Rossi 1980; Speare 1974). For example, changes in marital status, age and the introduction of children may lead to voluntary movement. In addition, the authors control for housing characteristics that are likely associated with mobility, including length of tenure, overcrowding, neighbourhood physical conditions and the extent of maintenance deficiencies in the housing units observed.

Using the independent variables described above Freeman and Braconi (2004) employ a logistic regression model that 'predicts the likelihood of someone moving.' The results indicate that low-income households in gentrifying neighbourhoods are less likely to move than low-income households residing elsewhere. However, the authors note that in-movers to gentrifying neighbourhoods register a higher socio-economic status than out-movers. The authors conclude that it is possible for neighbourhoods to gentrify without displacement providing in-movers comprise a higher socio-economic cohort than out-movers:

> Given the typical pattern of low-income renter mobility in New York City, a neighborhood could go from a 30% poverty population to 12% in as few as 10 years without any displacement whatsoever, providing that all vacated units are rented by non-poor households. (Freeman & Braconi 2004, p. 50)

The results of the study suggest that rather than accelerating the departure of low-income residents through displacement, the process of localized gentrification, at least in New York, brings a lower propensity of disadvantaged household out-movement. This confirms Kain and Apger's (1985) conclusions that normal housing succession is primarily responsible for neighbourhood change. Indeed, overall housing turnover may be slowed by the reduced mobility of low-income households:

> The most plausible explanation for this surprising finding is that gentrification brings with it neighborhood improvements that are valued by disadvantaged households, and they consequently make greater efforts to remain in their dwelling units, even if the proportion of their income devoted to rent rises. (Freeman & Braconi 2004, p. 51)

The authors acknowledge their findings may be influenced by the size of the area under study, and that low rates of mobility may be attributable to a lack of alternative housing in nearby areas. In relation to Freeman and Braconi's study, Newman and Wyly (2006) point out that areas identified as 'gentrified' neighbourhoods may have already experienced displacement of low-income households decades earlier. They also argue that non-gentrifying neighbourhood control groups in the study comprise some of the lowest-income areas with, consequentially, higher than average turnover rates. This creates a high basis on which to gauge mobility and therefore a distorted control standard.

In a later study, Freeman (2005) examined the extent to which gentrification is associated with displacement by examining mobility and displacement in gentrifying and non-gentrified neighbourhoods. This study employs a discrete time logistic regression model to determine the likelihood of displacement in a gentrifying neighbourhood. Freeman considers factors that motivate displacement such as situations where residents seek to reduce the size of their accommodation, reduce their rent, and other circumstances such as eviction, changes in marriage status, joining the military or other involuntary reasons.

The results of this study indicate that displacement and higher mobility play little if any role in the process of change that occurs in gentrified neighbourhoods. Rather, demographic change in gentrified neighbourhoods appears related to lower rates of intra-neighbourhood mobility and the relative affluence of in-movers. These results echo those found in the (Freeman & Braconi 2004) study, where little evidence of displacement in gentrified neighbourhoods is detected and in-movers to gentrifying neighbourhoods are found to have a higher socio-economic status than current residents. For this reason, Freeman (2005) suggests gentrification is, in fact, a process of in-movement:

> The so-called gentry have attracted attention in terms of describing who these people are. Overlooked perhaps is the extent to which changes in the characteristics of in-movers could be the more important force in determining the way that neighborhoods change. (Freeman 2005, p. 487)

Freeman argues it makes intuitive sense that in-movers rather than out-movers are the driving force behind neighbourhood change. Prospective residents are likely to be more sensitive to local characteristics when choosing a neighbourhood rather than whether they should move at all. Moving is costly not just in terms of time and money, but also the potential disruption to social connections and daily routines:

> Once people have made the decision to move, however, these costs take less prominence in the equation. The characteristics of the destination neighborhood are then likely to be relatively more important. (Freeman 2005, p. 487)

There are two significant aspects of Freeman's contributions to the literature and to the development of the present study. First, the empirical evidence demonstrates the importance of in-movers as the most significant contributors to demographic readjustment in areas that are subject to neighbourhood ascent; and second, the theoretical corollary that neighbourhood characteristics are instrumental in determining local demographic profile.

Ellen and O'Regan (2011) provide the most recent significant research in the area of gentrification and displacement. In this study, the authors address three issues concerning neighbourhoods that gain economically. The first concerns evidence of displacement, particularly among those with fewest resources; the second investigates the source of neighbourhood income change; and the third examines other changes that accompany neighbourhood income gains. The authors compare patterns of entry, exit and incumbent upgrading in low-income neighbourhoods that have gained economically compared to those in other low-income neighbourhoods that have not gained. The empirical findings support the prior works of Freeman and Braconi (2004) and Kain and Apgar Jr (1985) in providing no evidence of heightened displacement, even among the most vulnerable groups of original residents, and even in cases where neighbourhoods experience the largest income gains. Higher income households are an important source of income gains, but there is also evidence that some original residents experience income improvement. The authors state that ‘original residents remaining in a neighborhood report greater increases in their satisfaction with the neighbourhood than those remaining in other low-income neighbourhoods’ (Ellen & O'Regan 2011, p. 3). Finally, the study shows gaining neighbourhoods are more likely to avoid the loss of white households than non-gaining neighbourhoods and are therefore more racially stable.

Summary

Prior research, predominantly from the USA, concerning the extent of displacement in neighbourhoods transformed by public or private investment demonstrates there is considerable variability in the findings primarily due to definitional arguments and geographic differences. Nevertheless, there are three important generalizations from US research that can be made regarding residential sorting and neighbourhoods that have experienced ascent due to capital investment. First, in-movers to those neighbourhoods tend to be wealthier, white and more educated. Second, that out-movers are more likely to be poorer, non-white and renters. Third, the process of demographic transition in ascending neighbourhoods is slow. Finally, there is little consensus in the literature to support the view that neighbourhood ascension causes displacement, at least in the short term.

Most studies discussed in this section indicate a degree of residential stability in economically gaining urban areas. This suggests as part of the normal neighbourhood transition process existing residents endure greater financial hardship to remain at these locations (Chapple 2009). However, greater burden such as higher rent is unlikely to be sustainable in the long-term. One can expect, ultimately, communities that experience abnormal property premiums will undergo demographic transition. This highlights the limitation of previous studies, which derive little clarification, in this regard, due to their short-term analytical timeframes. The present study seeks to address this issue by focusing on mature (RTSC) locations where the effect of an attractor (rail accessibility) has been fully realized and (rail induced) property premiums reflect contemporary valuations of that attractor.

2.2.5 Neighbourhood demographic patterns: simulation models

Various computational models have been proposed in recent years. These models generally seek to simulate demographic transition in neighbourhoods that experienced transformation, particularly as it relates to gentrification. Zuk et al. (2015) identifies two general approaches: those that focus specifically on gentrification and those that consider residential decision-making and residential segregation. Simulation models can also be grouped according to their structure. Some have been classified as 'agent-based' or 'multi-agent systems', focusing on the arrangement of households into spatial patterns of settlement, while others are termed 'cellular automata models', which aim to capture patterns of change amongst fixed entities (Torrens & Nara 2007). In addition, there are various models used by planning agencies that simulate individual decision-making and the relationship of households and businesses with fixed characteristics in the urban environment (Johnston & McCoy 2006). The following is a brief review of some important contributions in this field.

Zuk et al. (2015) identifies four prominent simulation studies that deal explicitly with gentrification. First, (O'Sullivan 2002) invokes Smith's (1979) rent gap theory in specifying his 'cellular automata' model of gentrification in London. The author investigates the role of neighbourhood status in determining the 'gap' between the potential and capitalized rents and its impact on sales owner occupation and rental properties. O'Sullivan suggests that nesting neighbourhoods within their broader urban environment allows a better reflection of its position within the wider metropolitan hierarchy. Second, Diappi and Bolchi (2013) specify their model of gentrification in Milan by considering 'active agents', which includes investors, homeowners and tenants. In this approach, agents choose housing based on assessments of rent gaps, which are moderated by budgetary constraints. Rents are influenced by the provision of local amenities and distance to the CBD, while the availability of capital is determined by exogenous business cycles. Third, (Torrens & Nara 2007) specify properties in terms of 'fixed automata' aggregations and households are considered 'mobile automata'. In this model, the authors consider the impact of supply-based as well as demand-based drivers of gentrification. Predictive variables include economic and property market conditions, spatial amenities and amenity preferences. Finally, Jackson, Forest and Sengupta (2008) employ an ‘agent-based model’ to analyse Boston gentrification. These authors operationalize the gentrification model through demand-side consumer decisions only. The dynamics simulated by their model are driven by the interactions of professionals, non-professionals, students and the elderly, each of whom has a different preference for neighbourhood composition and amenity access and different ability to pay.

While the aforementioned studies are considered ‘exemplars of computational modelling’ relating to neighbourhood transition, they all suffer similar limitations. Zuk et al. (2015) notes that gentrification computational models are typically constrained by sufficient theoretical grounding. For example, while the O'Sullivan (2002) and Diappi and Bolchi (2013) studies adopt Smith’s (1979) rent gap theory they both neglect critically relevant concepts concerning the nature of demand-side influences. Hence, the model’s lack empirical detail, regarding specification of local attributes and the mechanisms that drive neighbourhood selection. An illustration of the latter is the absence of a variety of potentially important demographic factors involved in the process of housing decision-making. Previous empirical research has clearly demonstrated the effects of race and ethnicity, although these factors are neglected in most studies cited above (Charles 2003; Pais, South & Crowder 2012).

Other computational models explore the incidence of residential segregation. For example, Schelling (1971) theory of ‘tipping points’ attempts to explain the dynamics of residential segregation between races. The theory suggests that as the proportion of neighbourhood non-whites rise beyond a threshold, an out-movement of that group is likely to follow (Bruch & Mare 2006; Charles 2000; Schelling 1971). ‘Tipping points’ tend to vary with greater metropolitan racial attitudes and other city characteristics (Card, Mas & Rothstein 2008). However, Schelling (1971) suggests that both white and black thresholds ascribe to same-race neighbourhood preference, which means knowledge of ‘tipping points’ may be an important factor in successfully forecasting segregation.

A number of variations of the Schelling (1971) model have also emerged (Hwang & Sampson 2014). In this context, Bruch and Mare (2006) suggest that race preferences alone are not sufficient to account for the high levels of segregation observed in American cities and modify the model structure to include residential preference. Similarly, Clark and Fossett (2008) and Chen et al. (2005) go beyond simple race characteristics to include the interaction of a broader set of players.

Recently, researchers have begun to explore the relationship of land use and transportation and its influence on neighbourhood composition. For example, Dawkins and Moeckel's (2016) Simple Integrated Land-Use Orchestrator (SILO) examines the impact of housing programs and policies aimed at compact residential development in Washington, D.C. This simulator accounts for housing relocation constraints, the cost of transportation and travel times, but neglects racial considerations.

Summary

Urban computational simulation models demonstrate the variety of factors that can influence mobility decisions and sorting of population into localized demographically segmented groups. However, these models are largely concerned with consumer decision-making, and therefore focus on flows of people with little reference to the movement of capital. For this reason, they may not adequately capture the complexity of neighbourhood sorting dynamics in the context of rail infrastructure investment decisions.

2.2.6 The impact of transit investment on demographic composition

The following sub-section briefly outlines the theoretical perspectives concerning the relationship between rail hubs and residential sorting and explores the empirical framework used to model the impact of rail. This involves a review of the perspectives developed by economists, sociologists and demographers, who have examined the effect that accessibility to public amenities has on property values, and its consequences regarding the household location decision. In doing so, this analysis attempts to explain how demographic patterns nearby new or mature rail sites are likely to manifest in identifiable residential patterns.

Public transport is increasingly viewed as a desirable amenity for urban neighbourhoods. Household preference for transit-rich neighbourhoods derives from the ability of residents to easily travel between locations within the metropolitan area. Areas adjacent to train stations attract amenities which draw residents who may not even use public transit for their travel requirements (Bluestone, Stevenson & Williams 2008). Various studies confirm that properties within transit-rich neighbourhoods experience a premium effect compared to properties at similar locations without transit accessibility (Reconnecting America's Center for Transit-Oriented Development 2008). Growing premiums can, of course, lead to neighbourhood transformation. While noting that there is no substantial research to explicitly examine the relationship between transit investment and neighbourhood change, Chapple (2009) suggests that areas nearby rail stations may be particularly susceptible to transition.

Improvements to transit accessibility potentially 'price out' prospective as well as some incumbent residents as a result of rising property values and rental rates. Despite the importance of understanding the relationship between improved transit accessibility and changes to demographic composition, very few studies address the issue directly and there are virtually no studies that evaluate a comprehensive range of demographic features. Most of the literature concerning the impact of rail transit investment focuses on real estate value and not its indirect effects on residential sorting. Only recently have scholars begun to explore the relationship between rail transit investment and demographic shifts. These initial studies provide useful background information for the present dissertation.

As mentioned earlier, theoretical literature suggests that neighbourhood change in response to property proximity premiums is usually explained from either a demand or supply side perspective. Regarding the effect of transit, the demand side argument suggests that residential sorting may occur when an area obtains a new mode of travel that provides a viable alternative to the car. In-movers tend to bid up property values in order to access close proximity to an improved form of transport leading to higher value land use and potentially higher income residents. The alternative supply-side argument states that transit treatment causes demographic change when it counters pre-existing disinvestment patterns. Therefore, changes to demographic composition nearby transit investments are likely if there is a credible commitment to large-scale reinvestment in the area. Zuk et al. (2015) explains:

> Reinvestment in a disinvested neighborhood is likely when it appears that an actor (a state agency, financial institution or large land-owner) demonstrates a commitment to refurbish the physical environment at a scale capable of influencing the area's land or housing market. (Zuk et al. 2015, p. 22)

Empirical studies in this area are primarily concerned with establishing whether there exists a relationship between transit induced proximity premiums and residential sorting, and not always causality. These studies employ a range of methodologies and a variety of foci and their results are generally variable. Some of the main studies, in this field of research, and their contribution to the present study are discussed in this section.

2.2.6.1 Transit related sorting: empirical studies

Very few studies attempt to measure the relationship between the magnitude of rail induced property premiums and the proportional effect on residential sorting. One of the few is Grass's (1989) dissertation, which provides a useful methodological approach to understanding the effect of transit investment on neighbourhood change and a means to forecast the effects of new Metro rail investment in Washington DC.

Grass set out to determine if rail transit investment causes minority displacement. Given that income is considered a primary mechanism through which displacement occurs, Grass sought to estimate if increases in housing costs resulting from new transit investment force residents with the lowest incomes, and the least ability to pay, to find other lower cost housing.

Grass examines the relationship between the new Metro service and residential property values in both impact and selected control areas during the period 1970 to 1980. A mobility model is used to examine its effects on minority groups, and also provides a tool to predict the mobility rates for locations surrounding metro stops along a proposed Washington Metro corridor. Both models use the OLS technique to estimate these equations.

Grass's mobility model

Based on the premise that households adjust their housing consumption to desired (equilibrium) levels by relocating. Each search for new housing and move when expected gains from relocation outweigh the costs of finding and moving to a new location. If there were no costs, households would adjust their housing consumption immediately following a change in consumption requirements. However, the existence of moving costs means households do not necessarily respond to small cost changes. Households move only when the utility loss by not moving outweighs the cost of moving. Renters typically have a lower threshold in response to utility loss than homeowners due to the generally higher costs of moving associated with the latter.

Grass's aim is to gauge whether two neighbourhood demographic characteristics are susceptible to change following the introduction of rail accessibility: minority black homeowners and black renters. Mobility models for each of the black house-owners and renters that move are specified as follows:

$$MBLKH = f(PROPV, BLK, AG65B, OHUB) \quad (2.20)$$

and

$$BLKR = f(PROPV, BLK, AG65B, RHUB) \quad (2.21)$$

where:

$MBLKH$ = the percentage of black homeowners that moved from the station and control areas during a period of ten years following treatment

$BLKR$ = the percentage of black renters that moved from the station and control areas during that period

$PROPV$ = the average property value in the station and control areas

BLK = the percentage of black population in the station and control areas

$AG65B$ = the percentage of black persons who are aged 65 or more in the station and control areas

$OHUB$ = the share of black owner-occupied housing units in the station and control areas

$RHUB$ = the share of black rental occupied housing in the station and control areas

Property value equation

Grass uses the hedonic price equation with a dummy variable to represent impact and control area observations.

$$PROPV = f(DCC, TBATH, YSB2, BSQ, LSQ, DSTATION) \quad (2.22)$$

where:

$PROPV$ = average property value

DCC = the distance from the centre of the city

$TBATH$ = the average number of bathrooms

$YSB2$ = the average share of houses 10-40 years

BSQ = the average building size (sq. ft.)

LSQ = the average lot size (sq.ft.)

$DSTATION$ = dummy variable distinguishing impact and control areas

The author also uses a series of chi-square tests to determine if higher income households occupied impact areas relative to control areas following treatment. This enables the author to directly test the link between rail treatment, property proximity premiums, changes in residents' incomes and displacement.

The empirical results of Grass's study show the average property values increased by 19% in the impact areas compared to the control areas during the study period. This result indicates there is a significant difference between the property values during that time. Despite this, tests revealed no overall evidence to suggest that higher income households occupied station areas relative to control areas, in response to higher housing costs associated with new rail accessibility. However, the results show a 1% increase in the average property value leads to an increase in the percentage of black households that moved by 0.33%. Moreover, a 1% increase in property values leads to a 0.37% increase in black renter population. The results also suggest a significant relationship between the proportion of black population originally present at treated locations and the likelihood of black household movement. For example, Grass shows a 1% increase in the black population in a station area reduces the percentage of black households that move by 0.18%.

The effect of the age variable is also an important consideration in Grass's model. The results show a 1% increase in the percentage of blacks aged 65 years and older who reside at station areas leads to a 0.87% increase in the percentage of black households that move. Grass explains that because a high proportion of elderly citizens subsist on low or fixed incomes, whether homeowners or renters, they are often unable to cope with abnormal increases in property taxes or housing costs.

Grass's study is an important contribution to development of a methodological process to analyse the response of a particular demographic group to the introduction of rail infrastructure. The study is the first to incorporate property value as an independent variable in a model in representing the process of residential displacement. The significance of this type of model is that it can provide quantified information about residential sorting before a shock to housing costs occurs. Indeed, the model can be used to project changes in a variety of demographic characteristics in areas surrounding station sites that have not yet opened.

However, there are several problems with Grass's study that need to be addressed in formulating a suitable methodology for the present dissertation. First, and critical to the Grass approach, is the selection of incontestable impact and control locations. The choice of impact areas is based on three main criteria: economic stability; the existence of appropriate control areas; and the minimal negative effects of new rail infrastructure. These are three aspects that require subjective evaluations, which, in this case limit the selection to five stations from a possible 35 sites. Similarly, subjective evaluations are necessary to confirm the suitability of control locations. Using the approach employed by Grass, the researcher requires a high degree of certainty that selected neighbourhoods have neither experienced economic decline nor revitalization for reasons other than the introduction of new rail services. In both cases, these issues involve an onerous process determining compliance, which is not fully addressed in Grass's study.

Second, the duration of the study limits its potential value. Before and after studies, such as the one provided by Grass, merely investigate the process of sorting during a limited period in response to a shock caused by a specific event. This says nothing about the long-term implications of the event. While Grass's study timeframe appropriately examines the period beginning with the announcement of the project it concludes with only four years to assess its full impact. The problem with limited timeframe studies is that they may not reflect the new equilibrium position with regard to sorting. Indeed, questions remain: has the full magnitude of effects shown in Grass's study been realized? Has the process identified in the study reversed following the initial reaction to an abnormal property price rise?

Finally, the lack of indicia defining demographic profiles undermines the value of the study. This issue is common in much of the research that investigates the relationship between housing shocks and neighbourhood characteristics. Grass clearly demonstrates that resident age and the proportion of a racial group has important implications for sorting but neglects to test other aspects of demographic profiles which may either respond to, or moderate, the impact of such shocks. Johnston, Forrest and Poulsen (2001) points out that analyses concerning displacement and segregation should include several population dimensions. Similarly, Dunn, Kenna and Burnley (2007) argue that sorting is a complex multi-dimensional urban process that involves a broad set of variables.

In another study, Lin (2002) examines the relationship between the presence of rail transit and gentrification of inner-city neighbourhoods in northwest Chicago between 1975 and 1991. The findings show that property values adjacent to transit stations are 20% higher than those located a half-mile away, which therefore supports the hypothesis that transit access provides a spur to gentrification. Lin concludes that gentrification is ‘shown to have spread like a wave over time’, but that further analysis beyond the author’s research timeframe is necessary to capture the long-term effects of gentrification. A major weakness of Lin’s study is the choice of residential property values as an indicator of gentrification rather than any form of demographic indicator. This severely limits the value of research by excluding the indirect effects of proximity premiums on sorting.

A recent study by Kahn (2007) reveals that transportation investments may affect the capitalization of benefits [and therefore sorting] differently depending of the type of transit infrastructure delivered. The author uses regression analysis to estimate the impact of rail transit on income and the proportion of college graduates living in the study areas, which provide indicators of gentrification. The findings show that communities treated with new ‘walk and ride’ stations are more likely to gentrify than communities treated with ‘park and ride’ stations. This means that new public transit investment may not gentrify all recipient communities. Indeed, Glaeser, Kahn and Rappaport (2008) argue that transit stations may even act as a poverty magnet. This is because low-income groups are less likely to own cars and tend to place greater value on rail access. In support of this hypothesis, Kahn (2007) finds in some metropolitan areas the share of college graduates living in communities nearby new ‘park and ride’ stations tends to decline relative to control locations. This supports other findings that show wealthy communities often oppose the introduction of rail stations nearby their locations (Altshuler & Luberoff 2004; Bowes & Ihlanfeldt 2001).

The methodology applied to Kahn's (2007) paper involves both compromise and enhancements compared to earlier studies. As with Lin's (2002) paper, the indicators of neighbourhood demographic change are somewhat limited (Filion 1991; Walks & Maaranen 2008). However, unlike the other papers dealing with this subject matter, Kahn's study assesses localities over a lengthy timeframe and also takes account of time that neighbourhoods are exposed to rail transit.

Pollack, Bluestone and Billingham (2010) also show that transit can act as a catalyst for residential sorting. The authors attempt to address the criticisms of previous research, which frequently considered only a few characteristics. Their research focus involves a comparison of the study neighbourhoods and the corresponding metropolitan area to determine if patterns of demographic change at transit locations differ from changes in the greater urban region. Specifically, the study involves an analyse of changes in demographic, housing and transportation characteristics in 42 US neighbourhoods at 12 metropolitan locations first served by fixed guide-way transit between 1990 and 2000. For each neighbourhood, the authors investigate changes in population, racial and ethnic composition, in-migration, housing type and value, tenure, rent, household income, public transit use and vehicle ownership.

The study reveals that change in many newly treated neighbourhoods is similar to the patterns experienced in the corresponding metropolitan areas. However, the authors report evidence of some neighbourhood transition replicating the process of gentrification, if the latter is defined by housing costs and incomes. In these areas, the value of housing stocks tends to rise, residents become wealthier and there is more evidence of automobile ownership.

The findings show that neighbourhood changes are variable. The most prominent patterns show incomes and property prices tend to rise more rapidly and car ownership becomes more common than in the corresponding metropolitan area. The study reveals that increasing property values and rising incomes occur in most newly treated neighbourhoods. A negative consequence of these changes is rising rents, which creates higher household financial burden, for those with private leased accommodation. The study also shows that new transit access can set in motion a series of unintended consequences. For example, higher-income, car owning residents who are less likely to use public transit for their travel requirements can price-out core transit users, such as renters and low-income households, from transit-rich neighbourhoods (TRNs). These patterns of neighbourhood change can work against the goal of TRNs, which is intended to increase the use of transit systems (Pollack, Bluestone & Billingham 2010).

The study also shows that neighbourhoods are more susceptible to transition if they have a large proportion of renters. Indeed, the authors note:

> …when we specifically looked at the neighborhoods where the new stations were light rail—neighborhoods which, in our study, were more likely to be dominated pre-transit by low-income, renter households than those in the heavy rail and commuter rail neighborhoods—almost every aspect of neighborhood change was magnified: rents rose faster and owner-occupied units became more prevalent… (Pollack, Bluestone & Billingham 2010, p. 33)

On the other hand, the research finds no evidence that new transit inevitably results in changes to racial composition. Consistent with other studies the high retention of high-income minority households, together with in-movement of higher income, racially mixed residents, generally leads to wealthier post-transit neighbourhoods and largely intact racial composition.

Although their research did not conclusively detect displacement at treated locations, evidence of rapidly higher rents implies that incumbent renter households can experience greater burden with respect to housing costs. Also, as mentioned earlier, the authors find supporting evidence that neighbourhood revitalization can lead to higher car-ownership. In some neighbourhoods, new transit appears to reduce neighbourhood residency by groups with a higher propensity for public transport use. 'Utilization of public transit for commuting in this problematic subset of newly transit-served neighborhoods actually rose more slowly (or, in some cases, declined faster) than in the corresponding metropolitan area as a whole' (Pollack, Bluestone & Billingham 2010, p. 4).

Pollack, Bluestone and Billingham's study is a valuable addition to the literature. First, it places greater emphasis than most previous research on investigating the special patterns of transit induced residential sorting rather than simply the mechanisms that underlie change. Second, the context of new transit development, relating to either the type of transit offered or the locational attributes are shown to be important to the investigation. For example, studies of transit-oriented developments (TODs) that investigate changing demographic patterns can explain changing travel behaviour and therefore provides valuable information for policymakers and planners. This is illustrated by the observation that certain demographic groups, comprising core transit users, are attracted to well-planned TODs as part of the replacement process in gentrifying neighbourhoods. The authors also examine broader indicia of predictive neighbourhood change. Rather than restricting their analysis to housing prices and/or income they have recognize that other demographic characteristics can signify gentrification. Finally, the authors' study reveals the interaction of gentrification indicators may explain the magnitude of transit impact on neighbourhood change.

Pollack, Bluestone and Billingham's findings echoes those of Kain and Apgar Jr (1985) and Freeman and Braconi (2004) in providing no real evidence of involuntary displacement. The authors conclude their research reveals no strong evidence of disproportionate change in the racial composition of newly treated neighbourhoods. They suggest the high retention of high-income Black and Hispanic households, together with in-migration of racially mixed, higher-income residents result in an overall wealthier neighbourhood, but one with characteristics like the pre-transit model.

However, some studies suggest the potential for the unintended consequences of transit investment in terms of transit usage. These studies show that, while gentrification revitalizes many inner city and suburban neighbourhoods it often reduces transit accessibility of low-income households (Cervero & Duncan 2002; Knaap, Ding & Hopkins 2001). Pucher and Renne (2003) concur with these observations citing US national travel survey data, which reveals between 1995 and 2001 high-income groups registered a modest increase in urban rail travel while low-income groups recorded a modest decrease during the same period.

Another recent study indicates other undesirable outcomes of transit investment. Baum-Snow, Kahn and Voith (2005) examine transit usage at various urban locations in the USA that expanded their transit systems between 1970 and 2000. The authors find that incomes in recently treated areas are generally lower than the overall metropolitan district, and that income gaps often widen over time. Because newly treated areas become relatively poorer the authors speculate that public transit can act as a deterrent, rather than a catalyst, for neighbourhood revitalization (see also (Glaeser, Kahn & Rappaport 2008).

In contrast, Cervero and Duncan (2004) show the introduction of transit can provide a meaningful alternative to commuting and change the lifestyle of residents at nearby rail access locations. For example, in the San Francisco Bay area, research shows those living nearby transit are generally three to four times more likely to use transit amenities compared to residents at other locations (Bernick & Cervero 1997). Furthermore, a study of the Santa Clara County light-rail finds residents nearby rail stops are five times more likely to commute than residents county-wide (Cevero 1996). In the same study, 40% of survey respondents who move closer to transit stops indicate they are influenced by the presence of light-rail accessibility.

Other evidence shows some communities consistently experience positive transit usage changes. For example, residents at TODs generally have a higher propensity to use the local transit facilities.

These locations are typically geared towards transit usage by providing easy access and discouragement of automobile ownership, which is achieved by limiting car spaces at new apartment developments. A review of the literature concerning TODs shows that residents are likely to have lower automobile ownership rates, and without access to automobiles residents are more likely to walk or make use of the public transit system (Evans et al. 2007).

Cervero (2007) provides some useful insights into residential sorting at TODs. His study shows that low-income transit riders and wealthy travellers who choose to use rail transit are both well represented at planned TODs. He concludes that resident's travel behaviour at TODs is the result of both lifestyle preferences for residing nearby transit and planning policy. Overall, Cervero's model predicts that Asian American and Hispanics are more inclined to live near rail transit stations than whites, as are low-income households compared to high-income groups.

The residential sorting process described by Cervero, in relation to TODs, may account for the type of transition observed in other types of rail transit communities. Alluded to earlier, an understanding of demographic transition at revitalizing neighbourhoods requires not only identifying who are the out-movers, but also who are the in-movers at these locations. Freedman argues that what is generally '[o]verlooked…is the extent to which changes in the characteristics of in-movers could be the more important force in determining the way that neighborhoods change' (Freeman 2005, p. 487).

In a similar way, the characteristics of in-movers at RTSCs are likely to determine the demographic pattern of these locations. Hence, it is important to understand these characteristics if we are to predict the nature of communities that are likely to follow in urban societies due to our increasing focus on efficient mass transit systems. For example, if in-movers are younger, with smaller families and highly employed, their community needs will differ from locations where residents are older, have larger families and there is a high degree of unemployment. Furthermore, understanding likely changes to community profile may help predict the up-take of public transit at newly treated locations.

In their summation of the literature Pollack, Bluestone and Billingham (2010) report a reasonable volume of evidence to suggest that new transit stations and perhaps even the older transit stations can catalyse neighbourhood change. This leads to possible long-term displacement, greater racial homogeneity and populating by residents with the ability to pay higher rents or buy more expensive homes. Clearly this kind of process does occur at transit centres. However, it is equally clear that rail transit does not inevitably lead to gentrification and displacement of groups considered vulnerable. '[S]ome neighborhoods see little change, while others actually experience increased poverty' (Pollack, Bluestone & Billingham 2010, p. 19).

Another important observation is that estimations are consistently undermined by methodological approach. Pollack, Bluestone and Billingham (2010) note the tendency of researchers to limit the indicia when investigating neighbourhood transition, which significantly reduces the value of their research. For example, some studies include property values but not rent, or the proportion of college-educated residents but no other demographic characteristics. The authors argue, '[w]ith so few variables to analyse, researchers are often at a loss to explain the different patterns of neighborhood change observed in different neighborhoods or over different periods of time' (Pollack, Bluestone & Billingham 2010, p. 19). More research is needed regarding where, when and how this process occurs and what demographic factors are implicated in the process of neighbourhood transition.

McKenzie (2015) is one of the very few studies, and perhaps the only study, to examine a range of demographic patterns and their response to rail transit other than new treatment situations. The analysis includes six counties in the Washington DC area, each with at least one metro station. The demographic profiles of rail-accessible neighbourhoods in the six counties are then compared with the profiles of those that surround them. Using GIS, distance to the nearest station is calculated and assigned to residential blocks. Residents with rail access are defined as living within a residential block where the block centroid is within one half mile of a rail station.

Several characteristics of residents serve as economic and social indicators of neighbourhood change. These include resident's income, educational attainment, age, ethnic distribution, the presence of children and travel mode. McKenzie's findings indicate that rail-accessible neighbourhoods have higher rates of movers than non-rail-accessible neighbourhoods and that this influences the demographic profile of transit locations. Rail-accessible areas tend have a younger population; less families with children, residents with higher incomes and proportionately more university-qualified than other areas.

McKenzie provides a valuable insight into the relationship between rail accessibility and neighbourhood demographic composition. Two important drawbacks of McKenzie's research are the absence of hypothesis testing used to validate findings and the fact that there is no control for confounding factors. Despite these issues McKenzie provides the most relevant analysis available to compare the results of the present study. Therefore, chapter six of this dissertation considers McKenzie's findings and its contribution in more detail.

A final study, of profound importance in this area, is offered by Barton and Gibbons (2017). This study explores the question of locational attainment and the role of transit in the New York area. The authors build on previous research, which has had provided mixed results in addressing this question. In this regard, some studies find that neighbourhoods with a higher concentration of public transit are more likely to attract lower income households, due to affordability of private transport (Brueckner & Rosenthal 2009; Giuliano 2005; Glaeser, Kahn & Rappaport 2008). However, other research indicates that neighbourhoods with a greater concentration of transit services can be more attractive to higher income households, due partly to superior employment opportunities and partly the amenities they offer such as restaurants, bars and shopping facilities (Duncan 2011; Kahn 2007; Taylor & Ong 1995).

Barton and Gibbons' (2017) study determines whether the concentration of high-income residents in a census tract is spatially dependent. This allows for a test of statistically significant clusters due to the concentration of bus and rail transit. The authors note transit induced high-income clusters are not the only places characterized by high incomes. Their research aims to identify 'neighbourhoods where high incomes were the product of local neighbourhood forces converging to produce bias in income across neighbourhoods' (Barton & Gibbons 2017, p. 544).

The analytical approach involves both a longitudinal and cross-sectional random effects regression model and use data primarily from the 2000 and 2010 Census. The dependent variable is the medium household income per tract. The density of transit stops represents the primary predictor variable. The control variables are population density, the percentage of college educated, married and renters. Racial segregation is considered and measured through an entropy index. Building age is also included along with a dichotomous measure relating to the CBD. The cross-sectional results found that the concentration of rail transit predicted higher income levels. It rejected the notion that the poor were more likely drawn to transit rich areas due to the prohibitive cost of private transport. The longitudinal study showed that, when accounting for change over time and controlling for socio-economic status, only rail transit (and not bus transit) predicts higher incomes. However, the authors conclude that 'the role of transit, either rail or bus, was secondary to other larger processes taking place in New York…' (Barton & Gibbons 2017, p. 551). Nevertheless, the overall findings demonstrate that lower income households are relegated to neighbourhoods further from transit sources that facilitates commuting to work.

The significance of Barton and Gibbons' study is that it demonstrates the spatial dependency of income. It clearly shows that geographical locations with enhanced rail accessibility predict neighbourhood income patterns. It also shows that superior socio-economic status predicts the location of high-income neighbourhoods. Barton and Gibbons' study is restricted to the response of a single variable regarding the presence of rail transit. However, it stands to reason, investigation of the concentration of one demographic variable can be extrapolated to other socio-economic characteristics such as occupation, education employment status and so on. The spatial dependency of these and other factors are examined in the present study.

2.2.6.2 Temporal dimension of neighbourhood change

At this point it is worth a brief mention of the temporal dimension of neighbourhood change. Despite the emphasis of urban studies on change, it is interesting to note that the pace of change is particularly slow. Wei and Knox (2015) note that stability is the single greatest dimension of metropolitan change. This is supported by sociologist Fischer (2010) who suggests US residents have become significantly more rooted over time with just 12% moving in 2008, the lowest rate since 1948. Fischer explains that while people are moving less, those who do move, either 'forced by poverty or liberated by affluence' are effectively 'reinforcing the economic and cultural separations' which are already evident in the community (Fischer 2013).

Factors that may lead to movement include disinvestment in urban areas, suburban investment and changes in land use patterns. These are generally practices associated with government or business underwriting (Hirsch 2009; Levy, McDade & Dumlao 2010). This can lead to shocks which act as catalysts to changes in neighbourhood demographic composition. Even in neighbourhoods where change is precipitated by such an event, transformation may take decades to complete. It is with this in mind that the present research focuses on areas that have undergone change, due to rail treatment, and are now in equilibrium. This does not mean movement has ceased in these communities. While the investment-side catalyst has run its course, there remains an inflow of people who share an interest in rail transit and an outflow of people whom, for whatever reason, require a different residential setting. The primary focus of Stage 2 research in this study is to determine the extent to which there are similarities in the demographic concentration nearby rail access, and also areas that are considered beyond rail accessible.

2.2.7 Summary of mobility and sorting literature

Most recent theories relating to residential mobility assume that individuals engage in a rational, cost/benefit decision-making process. The earliest models argued that mobility is an investment whereby expected rewards exceeded the costs of remaining at the place of origin and the move itself. Subsequently, the mobility model has been elaborated to include the concept of 'place-utility' where location choice involves an assessment of the social and economic benefits that are most apposite for households. A recent innovation appearing in studies is incorporation of catalysts in the model, which involves identifying the source and estimating the magnitude of housing affordability shocks that potentially lead to movement. However, for the purpose of addressing the questions presented in this study, existing literature is severely constrained by its scope, for two reasons. Firstly, it provides limited understanding of long-term demographic changes as a result of proximity premiums and other physical changes to affected neighbourhoods. Secondly, the tendency of researchers to limit the indicia when investigating the effects of neighbourhood residential sorting.

The purpose of the present study is to estimate a quantitative case for residential sorting in response to the presence of transit and to generate a robust picture of demographic composition in treated areas. This study aims to investigate the possible influence of public rail infrastructure to determine if there is evidence of clustering, not simply in terms of ethnicity, at neighbourhoods surrounding rail stations. The objective is to compare the concentrations of groups at different types of rail hubs with other areas in the city. These comparisons can provide a relative sense of demographic segmentation and can test whether concentrations of specific groups at rail hubs are significant.

To date, little hard evidence exists about the nature or extent of localized demographic concentration at suburban centres with rail access. Responding to this void in the literature, the present study will consider two important ideas. First, that there is a positive relationship between rail accessibility and property values, and second, that this relationship reflects a consistent demographic pattern at neighbourhoods nearby rail stations. Therefore, this study is intended to reveal the characteristics of those who are willing and able to pay a premium for the utility derived from rail accessibility. The corollary is that it also provides a better understanding of those that occupy areas with no rail access. The latter either derive insufficient utility that warrants living at rail-accessible locations or are precluded by price.

3 Methodology

Following the New South Wales State election in March 2011, the new State Premier announced the government's intention to prioritize construction of Sydney's first Metro extending from the north west growth area, through the CBD and beyond to the south west. When completed the line will cover a total of 65 km and require an investment commitment of $20 billion. In November 2016, the government announced a further feasibility study to consider a 23 km metro between Parramatta and the CBD with construction due to commence in 2020. These projects represent Australia's largest infrastructure program aimed at transforming Sydney's aging rail network into a transportation centrepiece suitable for a modern global city. Yet, while the vision is laudable there is little known about the side effects of community transition at treated locations and what this means for stakeholders.

Stakeholders include the government, community groups and developers/planners. Government has the objective to provide a catalyst for increased labour productivity through transport connectivity and to generally improve commute times for Sydney residents while lowering motor vehicle usage. Community groups are concerned with matters that impact local communities such as social dislocation and other ecological issues. Developers and planners play a key role in delivering the residential, commercial and retail infrastructure to support communities responding to rail induced structural changes. Understanding the effects of rail induced community transition is important in assessing the prospects of successful investment. Hence, the purpose of this study is to address two important issues related to community transition at treated locations. The first involves an examination of property values in areas nearby rail stations in Sydney to determine the influence due to the presence of rail transit, and the second, involves an assessment of whether factors associated with rail, potentially influence the location decision of home-seekers and therefore the demographic patterns in these areas.

To date, little evidence exists concerning the influence of rail induced land value uplift and its relationship with demographic profile. Previous studies concentrate primarily on the effect of land value changes and affordability. A key finding from the literature review (Section 2.2) suggests that neighbourhood sorting in response to an increase in land values within specific urban localities is typically influenced by income inequality. The theory posits that those with a higher the level of financial compensation benefit from greater residential location choice compared to those with lower compensation (Reardon & Bischoff 2011; Watson 2009). Therefore, income inequality can lead to a degree of demographic fragmentation as home-seekers with higher incomes sort themselves according to their preferences and then control the local political processes that perpetuate exclusion of those that may differ in demographic profile (Reardon & Bischoff 2011).

Critics of new rail investment programs raise concerns that the 'well-off' often displace more vulnerable, less endowed residents rather than improving their social mobility by catalysing opportunities (Bridge, Butler & Lees 2012). Since income is presumed to be an important mechanism through which displacement and fragmentation of population occurs, it is expected that a rise in property values, associated with introduction of local rail services may force residents with limited financial means, or other circumstances, to seek lower cost housing in areas with less rail accessibility. While these are issues of immense importance to stakeholders, particularly government agencies, planners still have an obligation to deliver improved services and greater productivity to benefit the general populous. If the presence of rail services impacts the local community profile, questions remain, such as: Who benefits from rail transit services? Who are those displaced? What steps should government planning agencies take to minimize and mitigate disaffected elements in the community due to State sponsored change? Resolving these matters requires a far more comprehensive analysis of RTSC demographic profiles than previous research has to offer.

3.1 Approach: two stage analysis

The stated objective of this study is: *To determine the magnitude of rail induced residential property premiums across the Sydney metropolitan area and to reveal how, and to what extent, rail accessibility predicts the spatial distribution of demographic groups.* Addressing the objective involves two principal estimations. The first deals with determining the relationship between rail accessibility and property values. The second examines the relationship between rail accessibility and neighbourhood demographic characteristics. The results of these investigations show how, and to what extent, demand for rail-transit is internalized in the cost of housing and how the degree of rail accessibility determines the demographic patterns that emerge at RTSCs. These analyses are considered in two interrelated research stages.

In regard to Stage 1 research, several studies offer guidance for determining the impact of rail transit on property values (Landis et al. 1995). Techniques used to explain rail induced property value uplift typically involve established property pricing models, which separate the effects of housing and neighbourhood characteristics from rail accessibility attributes. These studies generally employ either longitudinal 'pre/post' or cross-sectional 'separation of effects' analytical techniques to determine the effect of rail transit.

'Pre/post' studies are said to offer a simpler method to establish causal links (Duncan 2011). However, they require access to longitudinal data, which is not (and certainly in this case) always readily available (Chatman, Tulach & Kim 2012). Another limitation of Pre/Post studies is that this method is best suited to identify differential property values relating to immediately before announcement of new rail transit and immediately following commencement of the service. The issue here, particularly in relation to residential sorting, is that the period often used to estimate property value adjustment is necessarily brief and therefore tends to under or overestimate the long-term differential. Indeed, there may be circumstances whereby community change moderates the value of new rail transit in a broader timeframe.

An alternative approach, taken in this study, is to use cross-sectional data and the 'separation of effects', which allows estimation of rail induced proximity premiums at various mature rail station locations. The assumption here is that community valuation of rail accessibility reflects the contemporary perception of the benefits associated with rail transit that is well grounded in long-term experience. Mature rail locations have already experienced changes to their local commercial infrastructure in response to rail treatment and sorting has settled to reflect the spatial distribution of people, in equilibrium. Therefore, assessment of mature rail stations permits population demographics to be considered independently from the impact of the initial rail investment.

Stage 2 shows how demand for rail manifests in the ascriptive characteristics of the local community. Limited prior literature in this field suggests that an affordability constraint is the primary mechanism that drives the relationship between rail accessibility and residential sorting. However, there are other contextual factors that may contribute to this phenomenon. This study proceeds on the basis that the combined price premiums and various other factors are likely to affect residential sorting at RTSCs. On this basis, the present research aims to identify the demographic groups that underpin rail induced property price premiums; to explain the circumstances of groups that are involuntarily displaced from rail-accessible neighbourhoods; and to identify, and explain the situation concerning the demographic groups that are otherwise less conspicuous at neighbourhoods nearby rail stations compared to other areas.

3.2 Stage 1: estimation of proximity premiums

As discussed, the first stage of analysis is designed to estimate the property price premiums associated with rail accessibility. The first two hypotheses are:

> H_{1a}: *In relation to the Sydney metropolitan area, there is no significant difference in average residential property prices due to rail station proximity.*

H_{1b}: Larger commercial complexes surrounding rail stations do not lead to higher local property values.

To test these hypotheses, it is necessary to adopt a methodological process that isolates the effect of various factors that lead to property price variations. This will require modelling in two phases. The first phase involves a ‘global’ regression model specified to test property price differences between concentric rail zones, representing areas with different levels of rail accessibility and their control areas encompassing locations with minimal rail accessibility. The second phase involves a ‘local’ regression analytical technique to determine whether there are exceptions to the estimates implied by the global average.

3.2.1 The property value equation

Following Debrezion, Pels and Rietveld (2011) methodology, the first phase of Stage 1 employs a multivariate HPM to estimate the effect of rail accessibility on house prices. The HPM is the standard tool commonly used to analyse house prices. The technique effectively gauges ‘consumer’ preference for different types of housing at different locations and then estimates property prices based on their attributes. It does this by disaggregating property value into its constituent characteristics. The proportions of these characteristics can then be modified to obtain estimates of each constituent’s contributory value. This process identifies the marginal utility derived by adding to, or subtracting from, a property’s hedonic features. Therefore, the HPM is able to estimate home-seekers’ willingness to pay for the aggregated values that form property prices. By controlling for a range of structural, accessibility and neighbourhood characteristics, this researcher is able to isolate and estimate rail induced property prices.

Residential properties can be considered ‘multidimensional commodities characterized by durability, structural inflexibility and spatial fixity’ (Chau, Ng & Hung 2001; So, Tse & Ganesan 1997). The constituent components of residential may therefore encompass both quantitative and qualitative attributes. The HPM assumes that market property prices can be expressed as:

$$P = f(S, A, N) \qquad (3.1)$$

where:

P = Property transaction price, as a function of the three categories of independent variables.

S = A vector of variables relating to structural features, such as the number of bedrooms, bathrooms, car spaces, building age etc.

A = A measure of location relative to important points of reference, such as public transport and employment zones.

N = Local environmental factors that influence quality of life.

3.2.2 Functional form

This research adopts a log-linear specification with the natural *log* of property prices as the dependent variable. This variable is transformed to ensure the plot of residuals follow a straight line and enable proportionate interpretation of the results. In addition, some independent variables used in this research are assessed for the appropriateness of log and quadratic transformation.

A thorough investigation of all independent variables, available for inclusion in the modelling process, is undertaken in Chapter 5. This includes an examination of potential multi-collinearity. Also, analytical diagnostics are used to determine the most appropriate functional form for independent variables. The results of these investigations are designed to provide a suitable model of 'best fit'.

3.2.3 Description of variables

A full list of potential variables for model specification is shown in Table 3.1 below. Each variable is theoretical justified and fulfils the requirements for data availability and reliability.

Vector	**Variable**	**Description**	**Source**
Dwelling Prices	$NPRICE$	Nominal transaction price	CoreLogic RP Data
	$APRICE$	Adjusted transaction price	CoreLogic RP Data
	$\ln(ADJP)$	Log of adjusted transaction price	CoreLogic RP Data
Structural	BED	Number of bedrooms	CoreLogic RP Data
	$BATH$	Number of bathrooms	CoreLogic RP Data
	CAR	Number of car spaces	CoreLogic RP Data
	$BLDGAGE$	Building age	Strata Plans, NSW Dept. Lands Title
	$BLDAGE2$	Building age squared	Calculated
	$UNIT$	Strata unit	CoreLogic RP Data
	$VILTH$	Villa/Townhouse/Terrace	CoreLogic RP Data
	ARP	Attached residential property	CoreLogic RP Data and ABS
	$FLFLOOR$	Full floor unit	RE Advertising
	LUX	Luxury apartment complex	RE Advertising
	LOT	Total lot size of strata plan	Strata Plans, NSW Dept. Lands Title
	$LV1$	Up to 3rd level	Various Property Reports
	$LV2$	4th to 9th level	Various Property Reports
	$LV3$	10th to 19th level	Various Property Reports
	$LV4$	Level 20 plus	Various Property Reports

Vector	Variable	Description	Source
Accessibility	*DISTSTN*	Continuous distance to the station	GPS
	$\ln(STN)$	Log of distance to the station	Calculated
	ZONE1	up to 200 mtrs from station	GPS
	ZONE2	201 - 600 mtrs from station	GPS
	ZONE3	601 - 1000 mtrs from station	GPS
	ZONE4	1001 - 2000 mtrs from station	GPS
	ZONE5	2001 plus mtrs from the station	GPS
	PARKING	Rail station parking	Transport for NSW
	LINES	Number of rail lines serviced by local train station	Transport for NSW
	CBD	Distance to the CBD	GPS
	$\ln(CBD)$	Log distance to the CBD	GPS
	COAST	Distance to the coast	GPS
	$\ln(COAST)$	Log distance to the coast	GPS
	$\ln(RBW)$	Log distance to the nearest recreational body of water	GPS
	MW1	up to 500 mtrs from motorway	GPS
	MW2	501 - 1000 mtrs from motorway	GPS
	MW3	1001 - 2001 mtrs from motorway	GPS
	MW4	2001 plus mtrs from motorway	GPS
	$\ln(MW)$	Log distance to the nearest motorway entrance	GPS
Neighbourhood	*WTRSIDE*	Water side location	GPS
	ADJPARK	Adjacent to recreational park	Various property reports
	SCHZONE	Within catchment of suburb's best performing school	GPS
	Pc2KPLUS	The percentage of residents earning $2000 pw plus	ABS (SA1 level)
	SA1POPDN	SA1 Population Density	ABS (SA1 level)
	MAINRD	Set adjacent to a main road	Roads and Maritime Services
	LESS100	Less than 100 mtrs to the rail line	GPS
	SEMPLOY	Size of the commercial complex by employment	NSW Bureau of Travel Statistics
	MAJREG	Major or Regional Centre classification	NSW Metropolitan Strategy 2007
	ASSAULT	Rate of assault	BOCSAR
	ROBBERY	Rate of robbery	BOCSAR
	BRKENTR	Rate of break and enter	BOCSAR
	MVTHEFT	Rate of motor vehicle theft	BOCSAR
	CENTRAL	Central District	Greater Sydney Planning Commission
	SOUTH	South District	Greater Sydney Planning Commission
	WESTCEN	West Central District	Greater Sydney Planning Commission
	WEST	West District	Greater Sydney Planning Commission
	SOUWEST	South West District	Greater Sydney Planning Commission
	NORTH	North District	Greater Sydney Planning Commission

Table 3.1 List of variables

3.2.4 Dependent variable

In this study, the dependent variable $(APRICE)$ comprises transaction prices of 11,912 properties taken from 23 RTSC locations and their surrounds, throughout the Sydney metropolitan area[4]. The observations include transacted properties during 2011 and, at most, one year either side. This is done to provide a sufficiently robust data set to test variances in the predictive variables. As previously mentioned, the dependent variable is expressed in log form ($\ln(ADJP)$), which enables interpretation of coefficients as proportionate changes attributable to predictors in the model. To account for inflation and fluctuations in the Sydney real estate market the dependent variable is standardised by applying the Sydney Unit Housing Price Index (HPI), available from the Australian Bureau of Statistics (ABS 2014), to the nominal unit price for the years before and after 2011. The adjusted price of properties is calculated by:

$$APRICE = N^{*}100/HPI \tag{3.2}$$

where:

$APRICE$ = Real price of a property at 2011 values

N = Nominal price of properties

HPI = Monthly price indices corresponding to the transaction date

3.2.5 Independent variables

The independent variables are those that explain house prices. These variables represent property structural features, the degree of access to desired locations and neighbourhood characteristics. Both continuous and dummy variables are used in the regression model. All estimated coefficients are based on observations from both high and low rail access households in the station locality. The following discussion provides details of each variable.

3.2.5.1 Structural variables

Structural characteristics of residences represented in the model include the number of bedrooms (*BED*), bathrooms (*BATH*) and car spaces (*CAR*). The predominant feature relating to structure that influences residential housing price is living space. The first two mentioned characteristics offer a suitable proxy for unit floor size, which is unavailable from transaction record data. Numerous studies indicate that the number of bedrooms (Fletcher, Gallimore & Mangan 2000; Li & Brown 1980) and bathrooms (Garrod & Willis 1992; Linneman 1980) are positively related to residential property values.

[4] The target locations for this study are discussed at length in Chapter 4.

Building age of residences is likely to have an impact on property prices and is therefore included in the list of independent variables. The literature reveals the relationship between dependent variable and building age is potentially non-linear and perhaps 'U' shaped (Clapp & Giaccotto 1998; Li & Brown 1980). This is because the aesthetic characteristics of older residences occasionally result in a price premium. Building age estimates are often included in the model as both nominal (*BLDGAGE)* and squared values (*BLDGAGE2)*.

Housing type is an important consideration for home-seekers choosing a residence. Units, apartments, villas, flats, townhouses and terrace houses, both Strata and Torrens title, are included in the data. These dwelling types are categorized as attached residential properties (*ARP)*. In some cases, (generally strata) property owners collectively share the cost of upkeep associated with common walls and common areas such as gardens, roofs, lifts and driveways. Only stand-alone houses (more than a metre apart) have been excluded from the data because of incompatibility in the way housing attributes are assessed, particularly in regard to the inclusion of land size.

It is important to briefly consider the implications of excluding separate-family dwellings. These properties are usually advertised with land size, which is often a significant part of property value. On the other hand, in the case of properties with communal ownership, land size is usually excluded from advertised building lots. However, in the latter case, it is commonly, but incorrectly, held that the low priority of land size disclosure means that it is irrelevant to strata lot valuation.

In fact, the price of a strata complex, for example, embodies the value of land upon which the complex is built, along with all other common area features. The initial sale price of a strata lot determines the 'unit entitlement' or shareholding the purchaser has in the total building complex. This indicates the lot owner's liability regarding maintenance costs (levies), voting power in a 'strata' scheme. Hence, the price of a strata lot is the value of the airspace it occupies along with a proportion of land and the superstructure that supports the building complex. Calculation of a strata property valuation is therefore similar to a separate dwelling. The latter is excluded from the data set simply because there is a lack of available data indicating land size for strata properties, which form the majority of properties in the accessibility zones.

The inclusion of villas and townhouses/terraces (*VILTH)* in the data set broadens the residential property types represented in this research. These properties may have similar characteristics to separate-family dwellings depending on land title arrangements. Townhouses and terraces with dwelling and attached land is often owned exclusively by the purchaser (Torrens title) and there is no common area. In other cases, shared driveways, landscaping, and car parking beneath the residential buildings, occupy the residual common areas. Irrespective of the ownership arrangements, families with children generally prefer these types of residential accommodation as an alternative to higher density unit living at the core of urban sub-centres.

The land cost component in unit developments is typically minimalized. This means that the price of two otherwise equivalent lots will differ according to the number of units in a complex. Larger complexes mean more units but not always a proportionately larger land size. Therefore, it is reasonable to assume that, ceteris paribus, the relative land component of property cost is inversely related to the number of units in a complex[5]. For this reason, this study includes a variable that represents unit complex size (*LOT*). This means the impact of land value on lot price is isolated to explain unit price differences in different sized complexes but otherwise similar units.

Luxury unit complexes (*LUX*) and full floor (*FLFLOOR*) dwellings are special cases that are likely to add premium value to unit residences. These categories emerge from an examination of anomalous standardized residuals in the data set and explained through follow-up investigation of real estate advertising. For the purpose of this study, luxury complexes are defined as those with a concierge, a swimming pool and gym as minimum conditions that satisfy this classification. An apartment that is full floor is one, which occupies a full level of a building complex, and it is described as having ‘360^{o} views’. These conditions are strong attractors and, therefore, factored into the final model.

Floor level is sometimes considered a structural and other times a locational (neighbourhood) attribute. Generally, units at higher levels command better views than those at lower levels and therefore likely to attract a price premium (Benson et al. 1998). In this study, floor level is categorized into four groups comprising: levels 1–3 *(LV1)*, the most common in metropolitan units outside the CBD; levels 4–9 inclusive *(LV2)*, encompassing the restricted height limits of most sub-centres; and two additional groups of 10–19 *(LV3)* and 20 plus *(LV4)*, which capture the remaining building heights. The latter are most likely found in large Major and Regional Centres.

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[5] This does not apply if zoning rules require alternative land/building ratios or where special life-style complexes are designed to specifically to cater for a particular market. In the latter case, there may exist a range of amenities such as outdoor pools, landscaped gardens and tennis courts that are located within the complex but independent of the residential buildings.

3.2.5.2 Accessibility variables

Locations with easy access to desirable community attributes are generally expected to incur residential property premiums. Modelling in this study is primarily focused on the relationship between property prices and areas of greater and lesser rail accessibility. However, other salient accessibility features are also examined, such as rail station characteristics that enhance the quality of public transport services. Also, the effect of distances travelled to the CBD, recreational destinations and motorway access are evaluated in this study.

Railway accessibility

According to Debrezion, Pels and Rietveld (2011), there are two important components of railway accessibility. First, there is a 'local accessibility' component, which measures the physical distance of a property location in relation to a railway station. Second, a 'regional accessibility' component that measures the level of train service provided by a station. Proximity to a station and its level of service are both considered qualities that potentially influence property prices.

For the purpose of this study, proximity to rail access is examined at discrete intervals and therefore represented as a binary variable. Here, the focus area is segmented into zones where the outer segment is treated as the reference (Bowes & Ihlanfeldt 2001; Grass 1992; McDonald & Osuji 1995; Voith 1993; Weinberger 2001). Zone analysis enables investigation of property price premiums associated with different levels of accessibility and provides sufficient geographical coverage to capture concentrations of socio-demographic characteristics. This approach facilitates the comparison of price/sorting effects, which are considered later in this study.

Zonal distances, used to measure the value of rail accessibility, vary amongst researchers and planners. Early Toronto research by Dewees (1976) suggests that a 'walk-up zone' with a distance up to $^1/_3$ mile or 530 metres is likely to encounter the largest price impact resulting from rail infrastructure. In her study of London's Jubilee Line, Chesterton (2000) applied a radius of 1,000 metres from the station as the outer extent of the rail catchment zone. In a Sydney study of the rail link between Chatswood and Epping by Ge, Macdonald and Ghosh (2012), 1,000 metres was also used to define the main impact area of new rail infrastructure. However, there are potentially multiple zones of common utility derived from rail accessibility that emerge in a concentric pattern.

In delivering transportation services, NSW government planning makes various assumptions regarding 'walk to' transport access. Guidelines for Sydney metropolitan transport specify that

90% of households should fall within 400 metres of a rail line or bus route. Transport authorities use multiples of 400 metres, such as 800 and 1,600 metres as key distances in network planning. However, '[the] empirical origin of these commonly used "rules of thumb" is unclear' (Daniels & Mulley 2011, p. 2). A major issue concerns the fact that measurements are based on straight-line distances, which means that actual walking distances may be substantially greater depending on the topographical features of an area. Another issue is that customers' walking distance preferences differ according to the mode of transport. These matters have important implications for the design of the methodological approach in this study.

Daniels and Mulley's (2011) analysis of transport data reveals that the mean walk distance from home to public transport is 573 metres. It also shows that the mean walk distance for trains is 805 metres and for buses, 461 metres. This suggests that the public is willing to walk relatively greater distances for train access. Furthermore, walk trips to train stations indicate a mode distance of 600 metres and conform approximately to a normal distribution compared to bus stops, which have a mode of 100 metres and a 'triangular' shaped distribution (Figure 3.1) The authors attribute the former distribution to the nature of train stations and land use surrounding stations. 'While train stations do have residential development around them, the immediate catchment is more likely to be non-residential with rail corridor uses, commuter parking, and commercial and retail uses' (Daniels & Mulley 2011, p. 11). They suggest that the observed small number of walk trips made within 200 metres of the rail station (the immediate catchment area) is likely to be influenced by these land use applications. Finally, the research shows that 97.6% of 'walk to' trips are made within 2 kilometres of a train station.

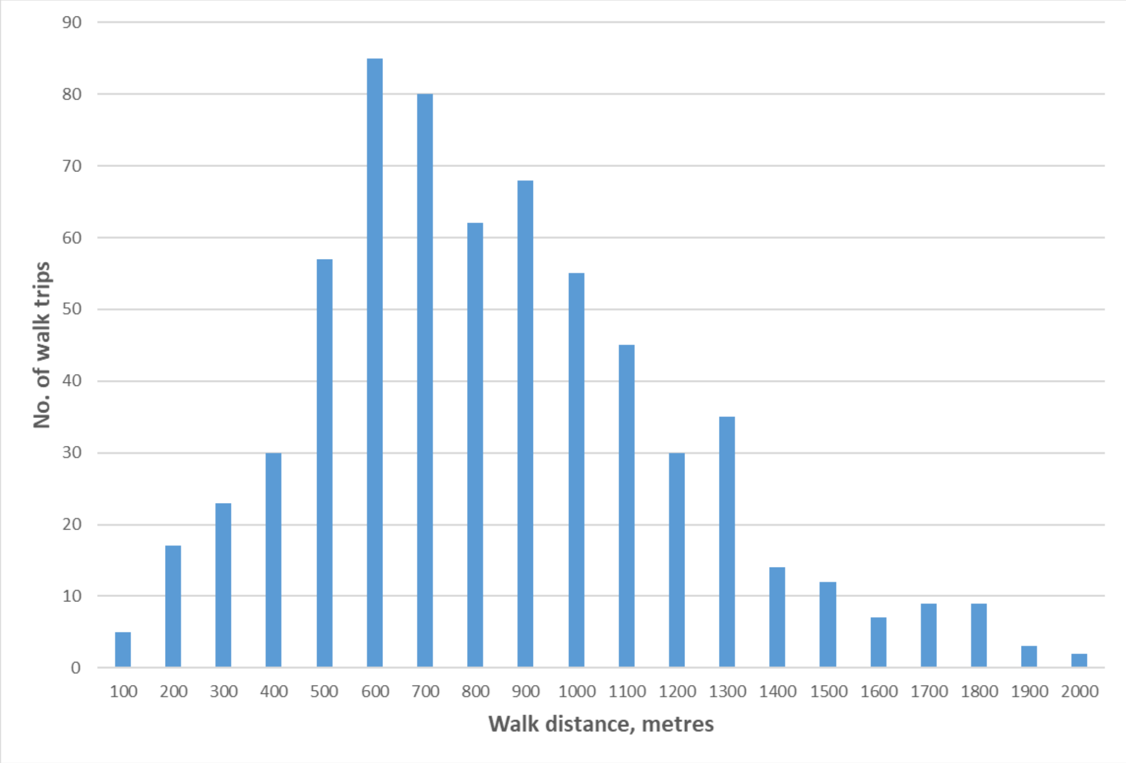

Figure 3.1 Distribution of walk distance to rail transport
(Transport Data Centre 2010 cited in Daniels and Mulley 2013 p.12)

Daniels and Mulley's (2011) analysis provides valuable insights for determining zonal distances. For the present study, 'walk to' (or 'network') distances are offered as a superior measure of zonal radii compared to direct line distances. Zones are constructed as follows: *ZONE1* (maximum 200 metre walk distance from the closest station entrance) represents the immediate catchment area surrounding a train station. This area is subject to the constraints and potentially negative externalities associated with the rail station and the surrounding commercial complex. *ZONE2* (201-600 metres walk distance) represents the primary catchment region where farther distance from the station is associated with a greater number of walk trips. *ZONE3* (601-1,000 metres walk distance) contains the mean walk distance of trips to the station. *ZONE4* (1,001-2,000 metres walk distance) is the outer limit of the catchment area in a range where trip frequency falls with greater distance from the station. *ZONE5* (Greater than 2,001 metres walk distance) constitutes an area of low rail accessibility, where rail stations have limited value. In this zone residents' first mode of transport required is highly likely to be other than rail, which is the case for all locations where rail access is considered remote.[6] In this study, *ZONE5* acts as the control location. The control zone provides the basis upon which to gauge the differences in property value at high access rail zones compared to areas with poor rail access. Ceteris paribus, the difference in property prices

[6] Zone 5: Distance to observations can be open ended. However, Zone 5 observations are closest to the target station as opposed to any alternative station.

between the high accessibility zones (*ZONE1,2,3,4*) is reasonably assumed to be the result of rail infrastructure.[7] For each zone variable the net effect of the rail accessibility benefits available to residents and any negative effects generated by the rail station determine the magnitude of the distance coefficient and its sign.

The level of rail accessibility is also considered a function of the station quality Debrezion, Pels and Rietveld (2011). Railway stations with higher network quality are presumed to have a relatively higher positive effect on the house prices. Two aspects relating to the quality of rail station are included in the analytical process. These are the provision of parking facilities (*PARKING*) and the number of destinations (*LINES*) that can be reached from a station. In this study, the provision of parking is indicated by a dummy variable that identifies locations with the availability public parking specifically designed to accommodate rail commuters. A continuous variable accounts for the number of the rail network lines serviced by a station.

In particular, the inclusion of *LINES* addresses the important aspects of Debrezion, Pels and Rietveld's (2011) station quality criterion regarding frequency and service connectivity. However, there are also two assumptions relating to the use of lines as a station quality factor. The first assumption is that a larger number of lines at a rail station provides a higher frequency of train services than a station with less lines. Second, a larger number of lines serviced by a station means a larger number of destinations reached without transfer. Given these assumptions, the *LINES* proxy variable accounts for the main issues relating to journey times.

Other accessibility features

In addition to rail accessibility, distances to the CBD *(CBD)*, the coast *(COAST)* and motorway *(MW)* entrances are potentially major determinants of property values. A measure of accessibility to the CBD is a variable commonly used in property value modelling. CBDs are typically the center of myriad activities that offer utility to metropolitan residents and provide a major source of employment opportunities. Therefore, closer proximity to the CBD is likely to be a factor that increases property prices (Debrezion, Pels & Rietveld 2011). Distance to the coast (*COAST)* is far less often used as an accessibility variable. However, posteriori knowledge derived from experience with the subject region suggests that it is an important consideration in this study. This is also supported by Abelson, Joyeux and Mahuteau (2013), who identify the distance to coast as a significant determinant of Sydney house prices.

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[7] Includes controlling for the size of the local commercial complex, see Section 2.1.5.5.

A final accessibility factor that warrants inclusion in the present study is motorway access. Motorways are a major competitor of rail-transit (Section 2.1.5.3). Debrezion, Pels and Rietveld's (2007) meta study shows that the inclusion of a motorway variable significantly reduces the impact of rail stations on property values. In this study, the driving distance represented by discrete intervals shown in Table 3.1 measures accessibility to motorways.

3.2.5.3 Neighbourhood variables

Neighbourhood variables included in the HPM account for local characteristics that influence property value. These variables are usually classified as environmental or socio-economic factors. Included in this study are location features that are known to generate positive or negative externalities.

Positive externalities are expected to flow from locations with appealing attributes, which enhance lifestyle, improve access to education and employment, and/or project an image of socio-economic advantage. Hence, properties situated adjacent to a recreational body of water (*WTRSIDE*), adjacent to a park (*ADJPARK*) and with lower crime rates may be expected to generate property premiums. Locations with higher incomes and wealth (*Pc2KPLUS*) are also expected to encounter higher property prices compared with other properties. In this case, benefits such as bespoke shopping, culinary options and peaceful environments are intrinsic to a higher quality of life and aspirational for those in poorer suburbs where the local ambiance is less agreeable. In addition, higher status neighbourhoods often feature higher rates of homeownership where residents have a strong interest in maintaining and improving their properties, given the size and importance of the financial investment (Gould Ellen & O'Regan 2008).

Another neighbourhood feature that is likely to weigh on property values is the existence of quality neighbourhood schools (Clauretie & Neill 2000; Jud & Watts 1981). Admission to top non-selective public schools is generally determined by catchment area rules. Areas within high performance schools' catchment zones (*SCHZONE*) are expected to contribute positively to property values and, therefore, an appropriate dummy variable is included in the analysis.

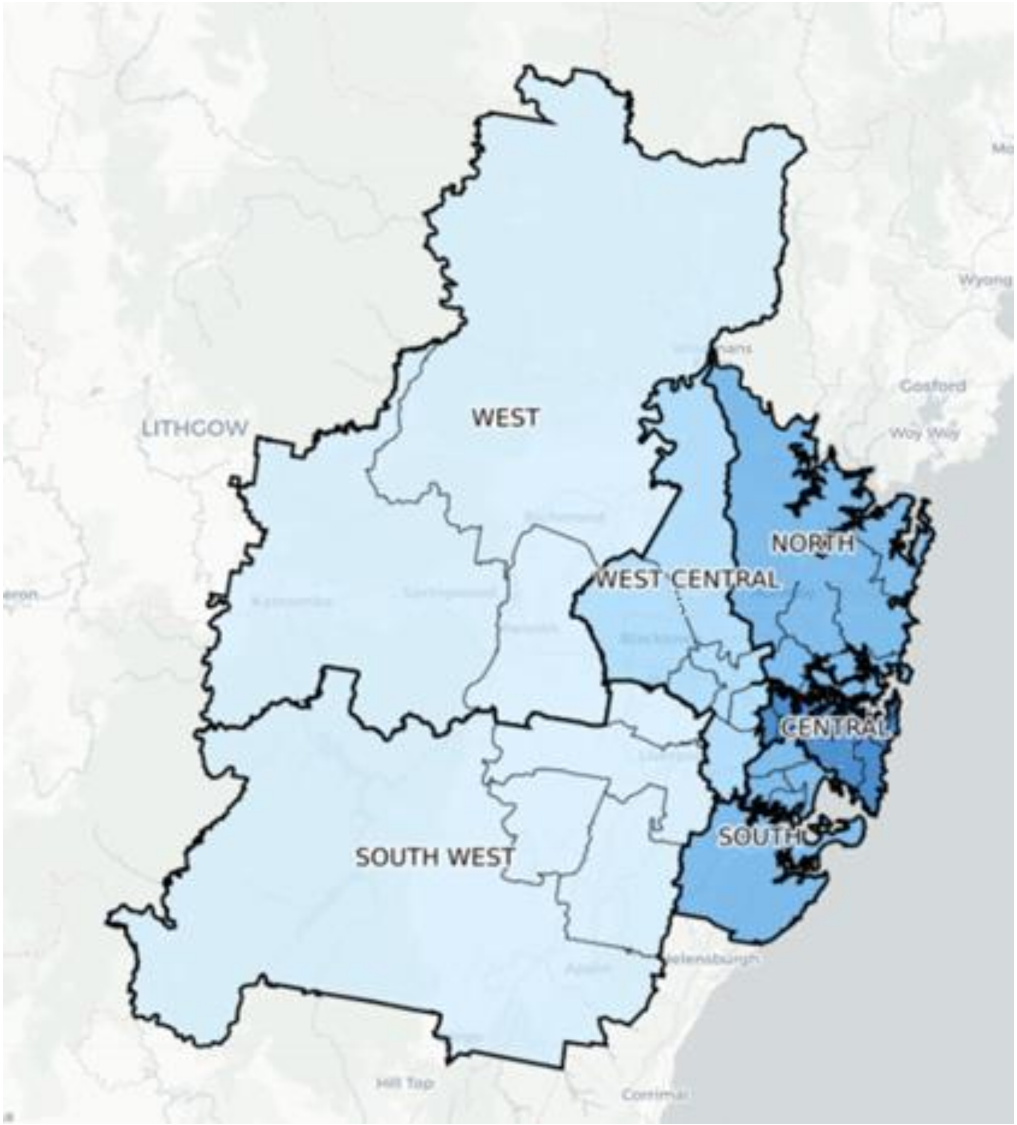
Other neighbourhood characteristics generate negative externalities. These include locational features that lead to forms of environmental pollution and the prevalence of crime. In this study, the dummy variables representing properties on a main road (*MAINRD*) and those within 100 meters of a rail line (*LESS100*) account for the negative effects of congestion and/or noise pollution. The rate of assault, robbery, break and enter and motor vehicle theft are used as proxies for crime

(*ASSAULT, ROBBERY, BRKENTR and MVTHEFT*). A higher proportion of crime in an area is expected to produce a negative coefficient.

At locations analysed in this study the dominant commercial complex, which includes shopping, commercial and public service facilities, surrounds the local rail station. Earlier discussion shows that close proximity to shopping facilities, which includes the provision of professional services, can positively affect residential property values as a result of reduced travel time and costs Des Rosiers et al. (1996). However, it has also been noted that properties very close to these facilities may experience disamenity due to the negative effects of congestion and noise pollution (Sirpal 1994). Des Rosiers et al. (1996) point out that larger sized shopping complexes may adversely affect property prices directly adjacent to these facilities. While the overall effect of nearby public services and employment opportunities on property prices is unknown, intuitively there is a positive relationship.

This study attempts to isolate the effect rail stations have on property prices from the influence of the surrounding commercial complex. In this case, an innovative control variable is used to account for the attraction of different sized commercial districts that surround rail stations (*place*). A proxy in the form of local jobs *(SEMPLOY)* is used to indicate the scale of the local commercial complex. The assumption is based on the following argument. A larger commercial complex offers more advantages than smaller centres due to the larger number of services offered by the latter and the greater prospect of employment opportunities. Theoretically, this means proximity premiums nearby rail stations with no commercial complex can be attributed entirely to the effect of rail accessibility. In the case of rail stations that have adjacent commercial complexes, proximity premiums may be shared by the benefits associated with access to both rail and the local services. The larger the commercial complex the less need for residents to commute in order to access services and employment opportunities. Hence, the *SEMPLOY* variable may help to explain some of the variations in the impact of rail found in previous research.

Finally, different metropolitan districts have different aesthetic appeal and, potentially, different land prices. The Greater Sydney Planning Commission divides metropolitan Sydney into a number of broadly homogeneous districts, which are represented in this study by dummy variables (*CENTRAL, SOUTH, WESTCEN, WEST, SOUWEST and NORTH*). Eastern districts, close to the CBD, coastal harbours, bays and tributaries, are typically considered more desirable locations than those farther west. Areas depicted on the map below represent Sydney’s metropolitan districts according to the Greater Sydney Planning Commission. The table that follows shows the districts that encompass the study locations referenced in this study.



Map 3.1 Sydney metropolitan districts
(Greater Sydney Commission 2016)

Metropolitan district	Study location
Central	Bondi Junction Ashfield Burwood Strathfield Lidcombe
North	Chatswood Gordon Hornsby Epping

Metropolitan district	Study location
South	Bankstown Kogarah Hurstville Sutherland
Central West	Blacktown Chester Hill Granville Parramatta
South West	Liverpool Campbelltown
West	Richmond St Mays Katoomba Penrith

Table 3.2 Metropolitan districts and locations included in this study

3.2.6 Model interpretation statistics

The analytical procedure, adopted in this study, is designed to generate regression functions of 'best fit'. A number of interpretation statistics test the power and performance of the models and relevance of the data. Various measures are employed to test model specification and performance, and the significance of variables used in the regression analysis. The robustness of the model is determined by using measures such as White's test of standard errors for heteroscedasticity, which establishes if errors have equal variance. Tests for multicollinearity are also conducted using variance inflation factors (*VIFs*). Predictors identified as highly collinear are excluded from the analytical process.

Following tests for heteroscedasticity and multicollinearity, the coefficient of determination or R^2 value is estimated to reveal the explanatory power of the model's independent variables in determining variations observed in the dependent variable. In addition, the adjusted R^2 is calculated to assess the model against alternatives. An *F-test* is also used to determine if the variables added significant explanatory power relative to the intercept-only model.

It is also necessary to perform a *t-test* of regression coefficients to determine whether changes in the predictor variable significantly alter the response variable. A predictor with a low *p*-value implies a meaningful addition to the model. In this research, the significance of regression coefficients is tested at $p < 0.10$, $p < 0.05$ and $p < 0.01$ levels.

3.2.7 Determining spatial variability

It is important to determine the existence of spatial non-stationarity. This reveals intricate patterns that may emerge from local estimates and tests the uniformity assumptions of the global model relating to causal relationships. In this case, local modelling becomes an important diagnostic tool used to indicate the limitations of the global model. This study employs the relatively new local modelling technique known as GWR, which is described in Section 2.1.7.

GWR improves analytical granularity by explaining the impact of rail stations over space. Specifically, GWR examines local processes that give rise to spatial dependency (spatial autocorrelation) and spatial non-stationarity. Hence, the difference between the global (HPM) and the local GWR model is that the former indicates an average effect over a region, while the latter accounts for spatial effects. Therefore, by accounting for spatial variations in the regression parameters GWR offers the potential to significantly improve our understanding of house price predictors.

Specifying the GWR model

GWR is effectively, an extension of the global regression model and therefore it is similarly important to establish the best equation for its particular purpose. Du and Mulley (2007) point out that it is not necessarily the case that the best global model leads to the best GWR model. Following the lead from these authors we have sought to calibrate a GWR model consistent with ‘sensible’ results. In this study, dummy variables, which may give rise to multicollinearity, are excluded from the model unless they convert to continuous variables. A stepwise approach is then employed to select the appropriate variables from the remaining variable options.

This study employs a semi parametric Gaussian GWR model described as:

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k (u_i, v_i) x_{ik} + e_i \quad (3.3)$$

where:

(u_i, v_i) are coordinates of the *ith* point in space

$\beta_k(u_i, v_i)$ is the realisation of the continuous function $\beta_k(u_i, v_i)$ at point *i*.

This means there is a continuous surface of parameter values and measurements, which can be taken at various points on the surface area to estimate spatial variability. The calibration of the model assumes that observations near location i have more influence on the estimation of $\beta_k(u_i, v_i)$ than observations farther away. Hence, the weighted least squares provide the basis for understanding the implicit relationship between location *i* and observations in its surrounding area. The GWR model uses adaptive spatial kernels to weight data points across the focus area. If the data are densely populated then spatial kernels with a narrow bandwidth apply, while areas where data are sparse, broader bandwidths are utilized. GWR software may be programmed to choose the optimal bandwidth by seeking to minimise the AIC, which gauges 'goodness of fit'. Overall comparing the AIC and the R^2 of the global and local models assess model performance. A superior model is indicated by a lower AIC (significant at -3) and a higher R^2 value. In addition, traditional hypothetical F statistics testing is used for Gaussian models.

Components of the original data set are used for the application of GWR. The model contains fields of dependent and independent variables together with latitude and longitude coordinates. Files used in GWR4 are text format and comma delimited (CSV). GWR4 has the facility to read dbase files and interfaces with ESRI databases containing geographic objects, including Statistical Area 1 (SA1) districts. ArcGIS mapping can, therefore, be used to visually identify how variables change over space. A full explanation of GWR's application to this research, derivation of its variables and diagnostics is provided in Chapter 5.

3.2.8 Transaction database and source: dependent variable

Secondary data are used for both Stage 1 and Stage 2 of this research. The dependent variable for Stage 1, in both the global and local model, is Sydney residential housing market sale transactions. To maximise compatibility of the data used in the study, the analysis is restricted to residential units (see Section 3.2.5.1). A total of 11,912 observations are taken from 23 locations (Chapter 4) for the focus year 2011 and for some locations, one year either side. These data are collected at the postcode level, and beyond if necessary, to provide sufficient distance to capture observations in all zones.

Classifying transaction data into zones facilitates estimation of the perceived value associated with rail station accessibility. GPS is used to estimate distances from sold properties to the train station. These estimations are based on 'walk to' distances, which account for geographical constraints. Data collection covers all residential unit transactions in the targeted postcodes area unless an alternative rail station is found closer to the observation point than the target station. This elimination process avoids the potential distortions that may occur if property premiums are associated with other rail stations in the system. In this study, the distances to as many as three alternative nearby stations are estimated. Observations included in the data set are only those where the target station is also the nearest station. In effect, this produces a corridor of observations, the shape of which is determined by the unique influence of the target station.

The transaction data source is RP Data Core logic. This company is selected from a possible four property databases including, Australian Property Monitors (APM), Residex and SQM Research. RP Data Core logic is a subsidiary of CoreLogic (USA) and is the largest property data and analytics company in the world. It also holds Australia's largest residential and commercial real estate database. The company captures property transaction price details and physical characteristics from various sources, including auction results, state and local government agencies and real estate agents. RP Data Corelogic supplies housing data and analysis to a broad range of commercial businesses and government agencies. The company also powers a number of property price apps including those provided by the Commonwealth Bank and the Bank of Queensland. Property indexes generated by RP Data Core logic have been used by the RBA for analytical purposes. The RP Data-Rismark home value index is the country's benchmark valuation index and is the only Australian property index used by Bloomberg.

Some data limitations concerning transaction prices and property details provided by the database suppliers have previously been raised. The issue concerns 'changing characteristics of the housing stock through renovations can have an impact on the sale price and lead to misleading data when used as an indicator of prices' (Setiadi, Atchison & Fin 2006). However, this has limited implications for the present research. The issue of renovations is far more relevant to longitudinal studies and to freestanding residential properties, which are not included in the present study. Renovated detached residential properties tend to result in only marginal price differences compared to nearby equivalent properties as most property value is captured in the building within which the residence is located.

This research study required some degree of data cleansing, which is typical of the pre-analytical phase of most research using proprietary housing data. Following Hanson's (2006) example from a study of Australian house prices, property details were removed if observations had:

> no valid contract date; undisclosed price or an inconsistency in the price recorded; missing postcode; negative or zero sale prices; property types other than a cottage, house, semi-detached, terrace, townhouse or villa; duplicate observations, in terms of all house characteristics, the date of sale and price. (Hansen 2006, p. 31)

Hansen also noted that some observations should be removed in order to 'reduce the influence of outliers and ensure plausible estimates of the implicit price relativities' (Hansen 2006, p. 31). Similar, appropriate cleansing has been undertaken in this study.

3.2.9 Data source: independent variables

The independent variables used in this research are compatible with similar HPM studies. However, this analysis introduces additional elements aimed at improving the precision of estimates and therefore some new data sources are required. There are also cases where important data from traditional sources is unreliable. In these circumstances, suitable proxies have been developed to ensure the integrity of the analytical results.

In regard to structural features, Australian data sources do not offer a consistent overall measure of dwelling size, which is commonly used elsewhere. Nevertheless, the number of bedrooms and bathrooms is considered a good proxy for internal unit size (Fletcher, Gallimore & Mangan 2000). In addition, the number of car parking spaces is also used to indicate overall property size. These data have been sourced, from RP Data CoreLogic.

Building age is excluded from RP Data CoreLogic. As a substitute, this study uses strata plan registration date, available from the NSW Department of Financial Services, Lands and Property Information Division. Strata plans are registered for each unit complex shortly after construction and before occupancy, and therefore provide a good estimate of building age. Strata plan registration dates have been manually extracted from the Department data files and used as a proxy for building age. Non-strata buildings ages are sourced from NSW Land Registry Services.

Building heights and floor levels are not available from RP Data CoreLogic. The absence of floor level information is overcome by visiting each complex, more than four stories, that have inconclusive information regarding floor level details. Buildings over four stories are generally distinguished in the raw data by the large number of units in the complex.[8] Buildings potentially higher than four stories are confirmed on Google Street View. In some instances, a common three-digit numbering system (the first representing floor level) provides the necessary floor level information. The remaining buildings are personally checked to ensure the floor level data are accurately recorded.[9]

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[8] Available from Strata plans, NSW Department of Financial Services, Lands and Property Information Division

[9] Those apartment buildings visited generally displayed apartment level details in the foyer. These were also double checked online. A small number that couldn't be verified were removed from the data set.

The analysis also considers the proximity of a transacted property to the best performing local school. School performance data are sourced from the NAPLAN National Report. This report publishes overall performance measured by schools' combined average results in reading, writing, grammar and numeracy. Schools are then ranked according to their performance. In this study, the location of the best performing school in each area is identified and GPS walking distances from all properties in the data set are calculated.

As discussed, residences with frontages onto main thoroughfares or close to rail lines potentially suffer from noise and congestion pollution and may influence property prices. For the purpose of this study, main thoroughfares are defined as roads with highway status or roads that transverse suburban area providing a major route for traffic between adjoining suburbs. Residential properties prices close to rail lines are mainly affected by noise pollution. Consultation with a number of real estate professionals produced a consensus opinion in regard to the potential negative influence of rail lines on property values. The general rule to emerge from this enquiry is that the noise effect extends perpendicular from the rail line to the second parallel road or 100 metres, whichever the closer of the two points. Data for both variables have been obtained manually by street sorting and GPS. In this study, dummy variables are used to identify properties situated on main thoroughfares and within 100 meters of a rail line.

Other independent variables such as the size of the commercial complex, population density and crime statistics are sourced from government departments or instrumentalities. The scale of the commercial complex is measured by local jobs data sourced from the Bureau for Transport Statistics (2011). The data are collected at the suburb level, which is more localized than the postcode. This means data captured focuses primarily on the commercial district surrounding the central location of each target area. Regarding information concerning the population density of each locality included in this study, the data are sourced from the ABS 2011 census, taken at the SA1 level. Finally, crime statistics are derived from the NSW Bureau of Crime Statistics and Research (BOCSAR), 2011 data.

3.2.10 Model specification and expected results

Each variable, identified for potential inclusion in the modelling procedure, is evaluated for relevance in explaining the impact of rail on house prices and evidence of multi-collinearity. In order to provide a cohesive view of the relationship between these variables, matters relating to model specification and expected results for Stage 1 research are deferred to Chapter 5.

3.3 Stage 2: the effect of rail accessibility on residential sorting

The focus of Stage 2 is to estimate the impact of proximity to rail accessibility on the socio-economic characteristics at twenty-three locations in the Sydney metropolitan area. This analysis is designed to address the research question *RQ2* posed in Section 1.4.2, which asks: *Does demographic profile of residents in neighbourhoods with rail access differ from that in neighbourhoods without rail access?* The hypotheses that stem from the research question relate to each of the demographic variables investigated in this study:

> H_{2a}: *The spatial distribution of residents, according to income, is associated with externalities relating to rail access.*
>
> H_{2b}: *The spatial distribution of residents, according to university qualifications, is associated with externalities relating to rail access.*
>
> H_{2c}: *The spatial distribution of residents described as professionals is associated with externalities relating to rail access.*
>
> H_{2d}. *The spatial distribution of residents described as unemployed is associated with externalities relating to rail access.*
>
> H_{2e}: *The spatial distribution of residents, according to average age, is associated with externalities relating to rail access.*
>
> H_{2f}: *The spatial distribution of residents described as Australian born is associated with externalities relating to rail access.*
>
> H_{2g}: *The spatial distribution of residents described as families with dependants is associated with externalities relating to rail access.*
>
> H_{2h}: *The spatial distribution of residents described as renters is associated with externalities relating to rail access.*
>
> H_{2i}: *The spatial distribution of residents, according to average motor vehicle ownership, is associated with externalities relating to rail access.*

As previously discussed, it is expected the pattern of some demographic characteristics of rail-accessible neighbourhoods will differ from those without rail access. There are three fundamental reasons why residential sorting may manifest itself in noticeably different patterns at rail-accessible locations. First, is the reasonable assumption that rail transit is of value to some, but not all urban residents. If residents at rail-accessible locations have similar life cycle and life-style characteristics this may manifest itself in concentrations of particular identifiable groups. Second, potentially higher property prices at rail-accessible sites may lead to affordability constraints that restrict some categories of residents occupying preferred residential locations. This may result in displacement of certain price sensitive groups in these areas and form concentrations of groups that are less sensitive to price premiums. Third, higher demand for property at rail-accessible locations can lead to greater population density which may, in turn, change the complexion of residential land use. Housing types that typically occupy locations nearby rail stations are, again, suitable for some urban residents, but not all. Each of these conditions is directly or indirectly associated with rail access and is likely to influence demographic patterns at rail-accessible sites. The following section formalizes the theoretical framework that directs our research.

3.3.1 Theoretical framework

Much of the current literature dealing with the migration of households in metropolitan areas concerns the response of home-seekers to rising house prices. These studies often focus on the issue of displaced minorities and a small set of characteristics that identify incoming gentrifiers. Previous studies typically address circumstances where relatively brief episodes of property value uplift at ascending neighbourhoods are the result of government or private revitalization projects, such as new housing projects. However, the location decisions of home-seekers are not entirely related to current development projects. Often, they are prompted by life cycle or life-style changes relating to marital status, financial circumstances, age, the needs of children and so on. In the context of day-to-day home seeker decisions, accessibility to rail stations is generally considered an important attractor. Yet the perceived value of rail transit to home-seekers depends on the importance of the connectivity it provides, the cost and efficiency of the service, and the availability and cost of alternative forms of transport. Home-seekers are likely to incur the cost of property premiums due to rail accessibility only if this amenity offers sufficient value to offset that cost. Hence, the perceived value of rail accessibility and its affordability are likely to influence the mobility decisions of both in and out-movers at rail-accessible neighbourhoods.

Demographic patterns at rail-accessible neighbourhoods are the net effect of in-movers and out-movers over time. In-movers are motivated by change in household circumstances whereby the utility provided by rail transit and the amenities available nearby stations outweighs the costs of the accommodation premium associated with these areas. Out-movers may also be motivated by a change in household circumstances which require different housing circumstances, or where the cost associated with close access to rail transit and accompanying amenities outweighs the benefits it provides.

A willingness or ability to pay for close access to rail is not always the result of an individual's change in circumstances. Rail induced property price rises can also have implications for both in-movers and out-movers. For example, an increase in property values at rail–accessible locations, due to a rising demand for rail services, can lead to displacement of financially vulnerable residents and deter the entry of others. In other circumstances, the introduction of new rail transit to a previously 'untreated' area may push up local property prices with similar effect. In both circumstances homeowners are likely to benefit from higher property prices although they are usually met with higher municipal taxes in response to increased land values. The impact on prospective and existing residents is more immediate for renters. Renters typically have a lower threshold in response to utility gain or loss due to the lower costs involved in relocating.

Mobility (or the relocation of households) is the mechanism by which residential sorting occurs. Mobility theory holds that rational households consider their specific set of circumstances in decisions relating to housing consumption. Alternative housing is assessed according to how well the structural, accessibility and neighbourhood characteristics of an area meet household preferences, within income constraints. The prioritization of housing needs, which initially drives the mobility decision, is largely determined by the motivation for relocating. Having established a preferred bundle of housing requirements the cost of housing becomes the key determinant of the household location decision. The search for housing and movement occurs when the expected gain from relocation outweighs the costs of searching for and moving to a new location. Therefore, home-seekers adjust their housing consumption to the desired equilibrium level by relocating residence.

A conceptual model derived from an early study by Grass (1989) provides a suitable theoretical framework for the analysis of household behaviour in relation to mobility decisions. In this model, the constrained utility maximization problem is given as follows:

$$MaxU_{(h)} \tag{3.4}$$

where:

$$U_{(h)} = U(H_{i,}X) \tag{3.5}$$

Subject to:

$$Y_h = P_H H_{i,} + P_x X \tag{3.6}$$

$U_{(h)}$ = the utility of household h

$H_{i,}$ = a bundle of housing services consumed at location *i*: $H_i = f(S_c, A_c, N_c)$

With S_c representing the structural and other physical characteristics of the property

A_c a set of accessibility variables

N_c, neighbourhood amenities and other features

X = a composite bundle of consumption items representing all other goods

Y_h = income of household h

P_H = a vector of prices for housing services. Hence, the amount paid for housing bundle H_i is $P_H H_i$.

P_x = the price of the composite good

Given a preferred composition of H_i, maximization of (2.18) subject to (2.19) yields the following demand function:

$$H_i = Q_D(P_H, P_x, Y_h) \text{ and} \quad (3.7)$$

$$H_i = Q_D(P_H) \quad (3.8)$$

if Y_h *and* P_x *are both constant.*

This shows both a change in household circumstances or location characteristics can stimulate movement. A change in the household circumstances of perspective in-movers and out-movers at rail-accessible locations can lead to a shift in demand for housing and/or their ability and willingness to pay for costs associated with rail access. Changes that occur at newly treated rail locations may also stimulate movement. For example, changes that lead to higher density housing may limit the range of housing options for some groups or proximity premiums associated with rail access may change making residential properties less affordable. For those locations treated with rail, an increase in the cost of housing can be substantial. In either case, higher costs associated with rail accessibility can lead to displacement. In equilibrium, the demographic patterns at rail-accessible locations indicate concentrations of those residents who value the amenities offered and have the ability and a willingness to pay the premiums associated with these areas.

3.3.2 Spatial distribution of demographic characteristics

The above analysis demonstrates the general principle that the utility offered by geographical locations and the costs of settling in an area are key determinants of residential sorting. In regard to neighbourhoods with high rail accessibility, the utility derived from rail transit is reflected in the location's property premiums. The utility offered and premiums incurred represent the benefits and cost of nearby rail access. These can be seen as the advantages and disadvantages, or the externalities, associated with close proximity to rail stations, which can have an important bearing on the location decisions of home-seekers.

It should be noted that other factors, apart from the availability of rail services, impact the conditions nearby rail stations and may influence home-seeker location decisions. For example, these areas are often characterized by their higher density living. As previously mentioned, housing types in these areas may be suitable for some but not all urban residents. However, higher density housing types are a secondary factor stimulated by the presence of rail transit, but not entirely attributable to rail. Similarly, the size of the commercial complex located nearby rail stations may simulate the effect of rail access. The assumption here is that amenities such as shopping, professional and public services and jobs source can have similar effect to that of rail transit. These factors should be considered when investigating the influence of rail on residential sorting. Controlling for population density and *place* helps isolate the direct effect of rail accessibility on the spatial pattern of demographic characteristics.

3.3.3 Model specification

A regression model, using data from ABS census tracts, is used to study the relationship between rail transit and the patterns of socio-economic characteristics at RTSCs. The model is calibrated with a variable representing 'walk-to' (or 'network') distance from rail stations using the same discrete intervals (zones) adopted in Stage 1. Additional variables include rail station service features, access to motorways and various other geographically based factors that are likely to influence location decisions. The final model is shown below:

$$Demo_c = f(Z1234, PARKING, LINES, ln(MW), SA1POPDN, SEMPLOY, ln(RBW), SOUTH, WESTCEN, WEST, SOUWEST, NORTH) \quad (3.9)$$

where:

$Demo_c$ = the concentration of a demographic characteristic

$Z1234$ = rail-accessible zones one to four inclusive. Zone five is the reference variable

$PARKING$ = a dummy variable for rail station parking

$LINES$ = the number of rail lines serviced by a rail station

$\ln(MW)$ = log of distance to motorway entrance

$SA1POPDN$ = SA1 population density

$SEMPLOY$ = size of the commercial complex by employment

$\ln(RBW)$ = log of distance to recreational body of water

$SOUTH, WESTCEN, WEST, SOUWEST, NORTH, CENTRAL$ = metropolitan districts: South, West Central, West, South West, North and Central. $CENTRAL$ is the reference variable.

Various tests to derive an appropriate functional form show the data conform to multi-linear regression assumptions. Hence, the model used in this study is based on the presumption that the right and left-hand side variables in the function have a linear relationship. This function can be expressed as follows:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_n X_{ni} + e_i \quad (3.10)$$

where:

Y = dependent variable

β_0 = constant term

β_1 = coefficient of the attribute X_1

i = the *ith* observation

e_i = error term

3.3.4 Definition of dependent variables

The demographic characteristics that constitute the dependent variables are listed in Table 3.3, together with other neighbourhood factors pertinent to the study. Each demographic characteristic and neighbourhood factor is estimated at the SA1 community level.

Dependent Variable	**Description**	**Definitions**
Pc2KPLUS	Percentage of people earning over $2,000/week.	
PcUNIQL	Percentage of residents with University or Tertiary education (Bachelor or higher).	
PcPROF	Percentage of professionals.	
PcUEMP	Percentage unemployed looking for full-time or part-time work.	
AVAGE	Average age of residents.	
PcAUSB	Percentage of Australian born.	
PcFAMDEP	Dwellings with family and dependent children as a percentage of the total number of dwellings.	A family is defined by the ABS ‘as two or more persons, one of whom is at least 15 years of age, who are related by blood, marriage (registered or de facto), adoption, step or fostering, and who are usually resident in the same household’ (ABS 2011).
PcRENTER	Dwellings rented as a percentage of the total number of dwellings.	
AVMVOWN	Average motor vehicles per dwelling.	
Other variables used in Stage 2 research		
PcUAF	Units, apartments and flats as a percentage of the total number of dwellings.	Unit, apartment or flat. This category includes ‘all dwellings in blocks of flats, units or apartments. These dwellings do not have their own private grounds and usually share a common entrance foyer or stairwell.’ The category also includes ‘flats attached to houses

Dependent Variable	Description	Definitions
		such as granny flats, and houses converted into two or more flats' (ABS 2011).
PcTWNVIL	Terrace house, townhouse or villa as a percentage of the total number of dwellings.	'Semi-detached, row or terrace house, townhouse, etc.'. These dwellings 'have their own private grounds and no other dwelling above or below them. They are either attached in some structural way to one or more dwellings or are separated from neighbouring dwellings by less than half a metre' (ABS 2011).
PcARP	Combined *Attached Residential Properties*. Units, apartments, flats semi-detached, row or terrace houses, townhouses and villas as a percentage of the total number of dwellings.	See notes for *PcUAF and PcTWNVIL* above.
PcTRAVT	Percentage of residents who travel to work by train, or train is used for the first leg in the residents' commute journey.	

Table 3.3 Variables used in Stage 2 research

Notes: 1. SA1 'not stated' or 'not applicable' are excluded from the total.

2. SA1 counts persons at place of usual residence.

3.3.5 Data collection: Stage 2

The ABS provides the socio-economic data used in Stage 2 analyses. The data set is available at SA1 level, which is the smallest spatial unit released by census authorities. SA1s generally have a population of between 200 to 800 people and collectively average 400. Suburbs usually contain multiple SA1s. High-density areas may feature many SA1s, some as small as a single block. Other less densely populated suburbs have few and geographically larger SA1s. Occasionally, 'zero SA1s' appear in the data. These are SA1s with nil or nominal population and may include commercial or industrial developments, educational campuses, parks, golf courses reserves, restricted areas or development sites. For the purpose of this study, 'zero SA1s' are excluded from the data set.

ABS TableBuilder is used to compile the socio-economic characteristics for each SA1 at all postcode locations included in the study. It should be noted that the data available for TableBuilder is subject to a confidentiality process to avoid releasing information that may allow identification of individuals, families, households or businesses. The process involves a technique known as 'perturbation'. The technique may randomly adjust cell values, which hold very small data. When applied, all cells are adjusted to prevent any identifiable data being exposed. These adjustments may result in some small-introduced random errors. However, most tables reporting basic statistics will not show discrepancies due to random perturbation. Contact with ABS sources assured this researcher that any effect from perturbation in data urban locations targeted in this study would be negligible if non-existent and there should be no impact on the integrity of the results from the spatial analysis conducted in this study.

SA1s are largely confined to blocks or small areas within the rail catchment area, which means classification into a number of zones corresponding to those in Stage 1 is feasible. However, in some cases SA1s overlap the zonal boundaries. In this study, each of the 11,912 transactions is assigned both its SA1 characteristics and zone number based on its specific location.[10] SA1 specificity for each transaction is made possible by latitude and longitude coordinates, which make possible an estimate of 'walk to' the station distance for the purpose of zone allocation. Similar to the procedure in Stage 1, the data set for Stage 2 includes only those SA1s where the target station is also the nearest station. This produces a corridor of observations for analysis, equivalent to that derived in Stage 1.

3.3.6 Expected results

The preceding discussion shows that the demographic pattern at neighbourhoods nearby rail stations is the result of in and out movement of residents in response to the benefits and disbenefits encountered at these locations. Residential sorting may be negatively influenced by higher property values nearby rail stations. However, whether proximity to rail stations generates sufficient price variation to influence residential sorting is dependent on the magnitude of that impact (Stage 1) and the sensitivity of socio-demographic characteristics to these price impositions. Indeed, it is feasible that the pattern of socio-demographic variables is unaffected by property price constraints and yet still negatively influenced by proximity to rail stations. Given the complexity of the relationship between rail station proximity and residential sorting the outcome is not easily predicted. The matters of expectations and outcomes are again dealt with in Chapter 6, which adopts a step by step approach to explain the intricacies of the relationship between the pattern of sorting and rail transit.

[10] The matter of SA1/Zone overlap is discussed further in Chapter 6.

4 Study Area Background

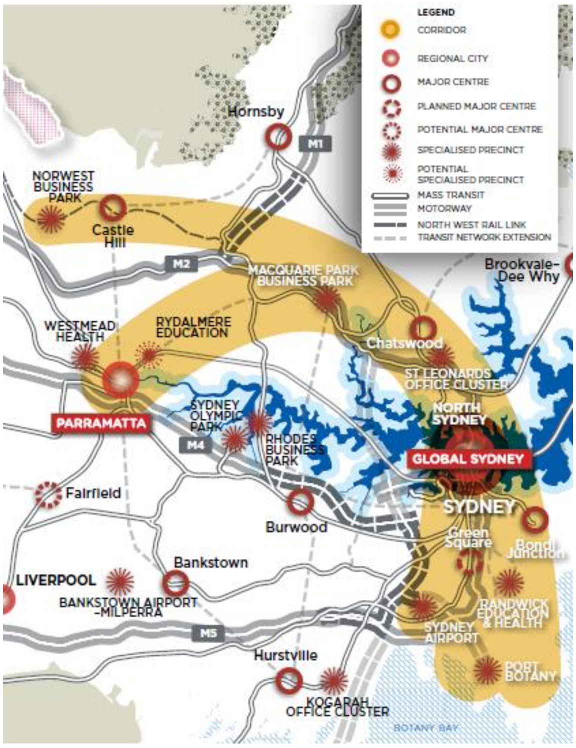
A considerable volume of past research indicates that urban sub-centres subject to property value uplift encounter changes to their local demographic profile. Changes in value emerge from a revaluation of neighbourhood attributes in response to various catalysts, including public investment. The literature suggests that, in these circumstances, changes in affordability can lead to neighbourhood income inequality and other demographic shifts, because better-off households are able to sort according to their preferences and less well-off are subject to displacement (Reardon & Bischoff 2011; Watson 2009). However, the literature also explains that the process of sorting is slow (Wei & Knox 2015), which means that evidence of sorting is best observed, not at locations that recently experienced changes to their attributes, rather, at those that have had sufficient time to fully evolve in response to such changes. For this reason, metropolitan Sydney is chosen as a suitable urban location to conduct research into the sorting effect of rail transit. It is a city with an effective rail system, which is valued by the community it serves, but sufficiently mature to allow long-term residential sorting and the emergence of distinctive demographic patterns at locations surrounding rail access sites.

This chapter provides background information relating to the Sydney metropolitan region and the specific locations that form the focus of this study. It begins with a brief profile of the City of Sydney and a review of the city's metropolitan strategy. This is followed by an overview of its rail network and details of new transit projects. This chapter also shows how communities are differentiated for the purpose of investigating the impact of rail infrastructure on property valuation and residential sorting at different location types. Finally, the chapter contains the descriptive statistics of these areas when grouped according to district and centre of strategic importance.

4.1 Sydney and its metropolitan strategy

Sydney is designated an Alpha+ Global City, second tier to London and New York (GaWC 2012) and has an economy larger than Singapore, Shanghai and Hong Kong (Infrastructure NSW 2012). Sydney currently has 5,230,000 residents and an annual growth rate of 1.8% (ABS 2019). An additional 1,800 inhabitants each week presents a major challenge for the state government in providing job creation, residential accommodation and sufficiency of transport infrastructure. With limited options available for city centre or greenfield expansion, policymakers have opted for land use intensification resulting in the emergence of a polycentric urban environment and fostering urban transit hubs, particularly those with rail access. In addition, zoning regulations have been implemented to encourage residential accommodation nearby public transport infrastructure at these locations. Urban hubs are the focus of the present study, which investigates the link between rail induced property premiums and the pattern of demographic characteristics.

A signature feature of Sydney's current development strategy is the GEC. The GEC involves the interconnection of urban sub-centres, specialised employment zones and the CBD in order to disperse job opportunities along with retail and cultural facilities throughout strategic corridors in the Sydney metropolitan region (see Map 4.1). The GEC extends from the Norwest Business Park and Parramatta, through North Sydney, the CBD to the shipping port and airport at Botany. The region employs over a million people (Infrastructure NSW 2012) and contains a high concentration of industries that contribute to Sydney's global significance including technology, finance, health, higher education and other knowledge based industries. A major feature of the GEC strategy is the provision of a future rail service that will connect the Norwest Business Park with the CBD as part of the Northwest Metro project.



Map 4.1 Sydney's Global Economic Corridor
(NSW Department of Planning and Infrastructure 2013)

4.2 Sydney rail network, new rail infrastructure and alternative motorway developments

The Sydney network operates trains in the greater Sydney suburban area bounded by Emu Plains; Berowra; Waterfall and Macarthur. Historically, the Sydney rail network developed along axial lines emanating from the city centre. Today, the network comprises seven main routes operated by Sydney Trains, a subsidiary of the state-owned Transport for NSW. Sydney's urban rail transport is considered a metro-commuter hybrid. Headways at the inner-city core of the system reach high frequencies and use tunnelled right-of-way and grade separated tracks with interval services, which typifies metro systems. However, once beyond the CBD the network operates on shared tracks combining intercity and freight operations on most routes of the middle to outer suburbs. These shared operations result in slower and lower frequency scheduled services, which are characteristic of commuter systems.

Despite the drawback of shared lines and the resultant slow travel speeds, the state government has consistently delivered high quality rolling stock to enhance customer travel experience. The bulk of Sydney suburban rolling stock currently comprise the 'Millennium' train, which entered service in 2002, and the 'Waratah' introduced in 2011. The latter, which now constitutes more than half the Sydney train fleet, features state-of-the-art inclusions such as 'walk through' carriage design, comfortable seating, air-conditioning that adjusts to the outside temperature and the number of passengers on board and a world first hearing loop system to optimize audio quality.

4.2.1 Main rail routes

The first railway constructed in Sydney was between the city and Parramatta and opened in 1855. The vast majority of the remaining rail stations were built prior to 1939. There have been few significant additions to the rail network since that date. The more recent projects include the construction of the City Circle, completed in 1956; the Eastern Suburbs line in 1979; the opening of the airport line coinciding with the Sydney Olympics in 2000; and the Epping/Chatswood rail link in 2009. The current configuration of the Sydney Trains network is shown in Map 4.2.

Map 4.2 Sydney suburban rail network
(CityRail 2016b)

Line colour, number and name		Between
T1	North Shore, Northern & Western Line	Central and Berowra via Gordon Central and Hornsby via Macquarie Park Central and Emu Plains, Richmond or Epping via Strathfield
T2	Airport, Inner West & South Line	City Circle and Macarthur via Revesby and either Sydenham (peak) or Airport City Circle and Leppington or Campbelltown via Strathfield and Granville City Circle and Liverpool via Regents Park
T3	Bankstown Line	City Circle and Liverpool or Lidcombe via Bankstown and Sydenham
T4	Eastern Suburbs & Illawarra Line	Bondi Junction and Waterfall or Cronulla via Central
T5	Cumberland Line	Schofields and Campbelltown
T6	Carlingford Line	Clyde and Carlingford
T7	Olympic Park Line	Lidcombe and Olympic Park, some services between Central and Olympic Park, particularly during special events

Table 4.1 Sydney suburban rail network route detail
(CityRail 2016a)

Most lines pass through Central Station, which is also the terminus for NSW TrainLink regional services. T1 North Shore and Northern Lines provide most of the northern services and include a branch to the outer western districts. Trains originating at the T2 Airport, Inner West & South Lines and the T3 Bankstown Line pass through Central and connect with the City Circle serving the Sydney CBD. The T4 Eastern Suburbs and Illawarra Lines emerging at Waterfall and Cronulla pass through the CBD and continue to Bondi Junction in the city's east. The T5 Cumberland Line serves the greater Western Sydney district and provides access to the Regional Centre of Parramatta. Finally, the T6 Carlingford Line and T7 Olympic Park Line provide suburban shuttle services linked to the main east/west trunk routes. The TrainLink intercity network extends the metropolitan rail system to the Hunter, Central Coast, Blue Mountains, Southern Highlands and South Coast regions.

4.2.2 Rail patronage

Sydney's metropolitan rail services have experienced consistent passenger growth (see Figure 4.1) averaging approximately 1.4% annually to the decade ending 2011. This is slightly above Sydney's average population growth of 1.12% during the same period (ABS 2016). Table 4.2

compares the volume of traffic between the various rail lines. This shows the dominance of CBD passenger traffic and highlights importance of the main trunk routes that carry passengers on the Northern, Western and Southern (Illawarra) Lines. Patronage on the relatively new Airport and the Macquarie Park link line has grown substantially since they opened in 2000 and 2009, respectively.

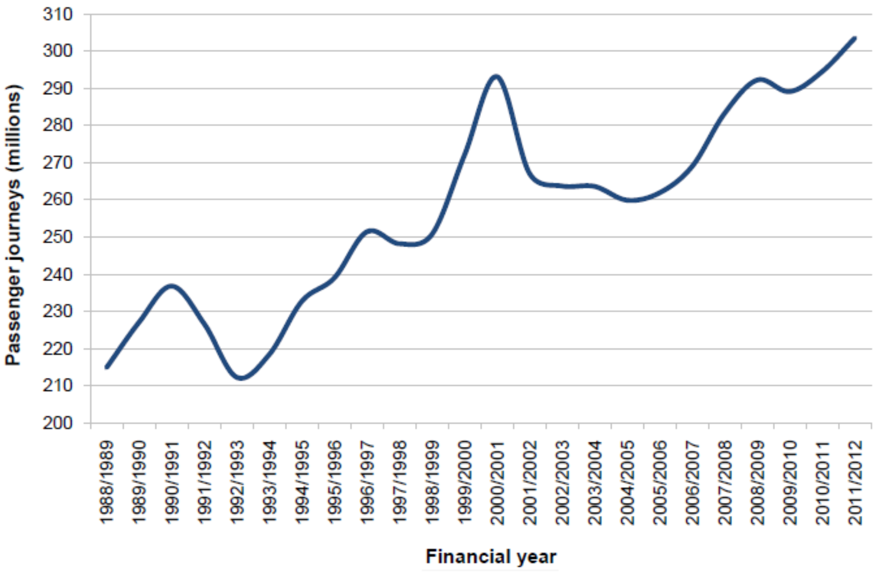


Figure 4.1 Annual CityRail passenger journeys since 1988–89
(NSW Bureau of Transport Statistics 2012)

Line	Change over 5 years 2006 to 2011	Annual average growth rate	Journeys 2011
CBD	9.8%	1.9%	33,683,575
Eastern Suburbs	12.7%	2.4%	11,284,998
Airport	79.6%	12.4%	4,496,687
Illawarra	13.4%	2.5%	30,239,560
East Hills	11.5%	2.2%	17,469,428
Bankstown	14.6%	2.8%	16,356,279
South	9.8%	1.9%	16,230,015
Western	12.3%	2.4%	36,058,613
Carlingford	-8.9%	-1.8%	288,589
Inner West	12.5%	2.4%	20,668,177
Northern via Macquarie Park	88.7%	13.5%	5,166,708
Northern via Strathfield	36.7%	6.5%	10,285,992
North Shore	9.8%	1.9%	28,892,709
South Coast	-2.7%	-0.6%	3,220,602
Southern Highlands	5.1%	1.0%	495,451
Blue Mountains	-5.1%	-1.0%	2,582,848
Central Coast	1.0%	0.2%	5,879,468
Newcastle	13.0%	2.5%	2,096,680
Hunter	-0.1%	0.0%	779,081
Olympic Park	72.6%	11.5%	257,305
Other	11.0%	2.1%	52,781,482
Total	**13.1%**	**2.5%**	**299,214,247**

Table 4.2 Patronage by line
(NSW Bureau of Transport Statistics 2012)

4.2.3 Network stations

There are 178 stations in the Sydney metropolitan area serviced by 2,191 carriages (excluding 574 attached to the NSW TrainLink fleet), operating on 961km of electrified track. Figure 4.2 shows patronage for the 40 busiest stations within the network. The station patronage data suggest the greatest volume of passenger movements take place either at locations within or close to the global CBD, at large commercial sub-centres or at locations with a high level of transport interchange and direct rail connectivity.

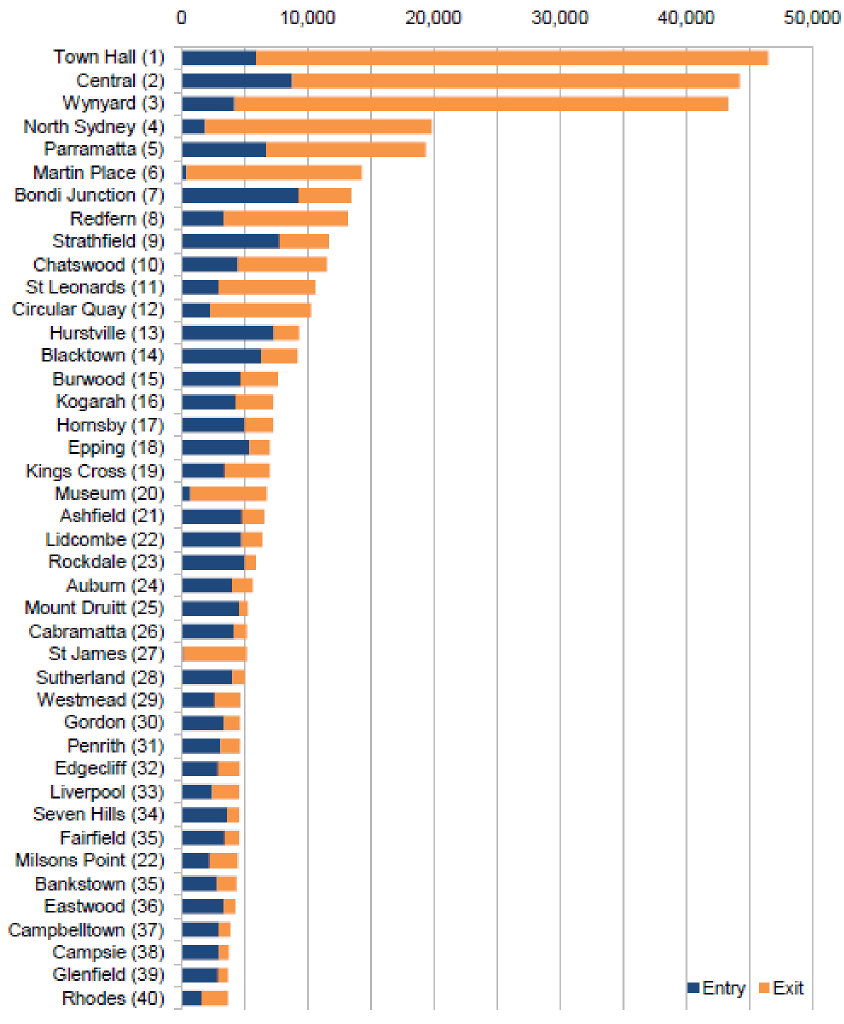
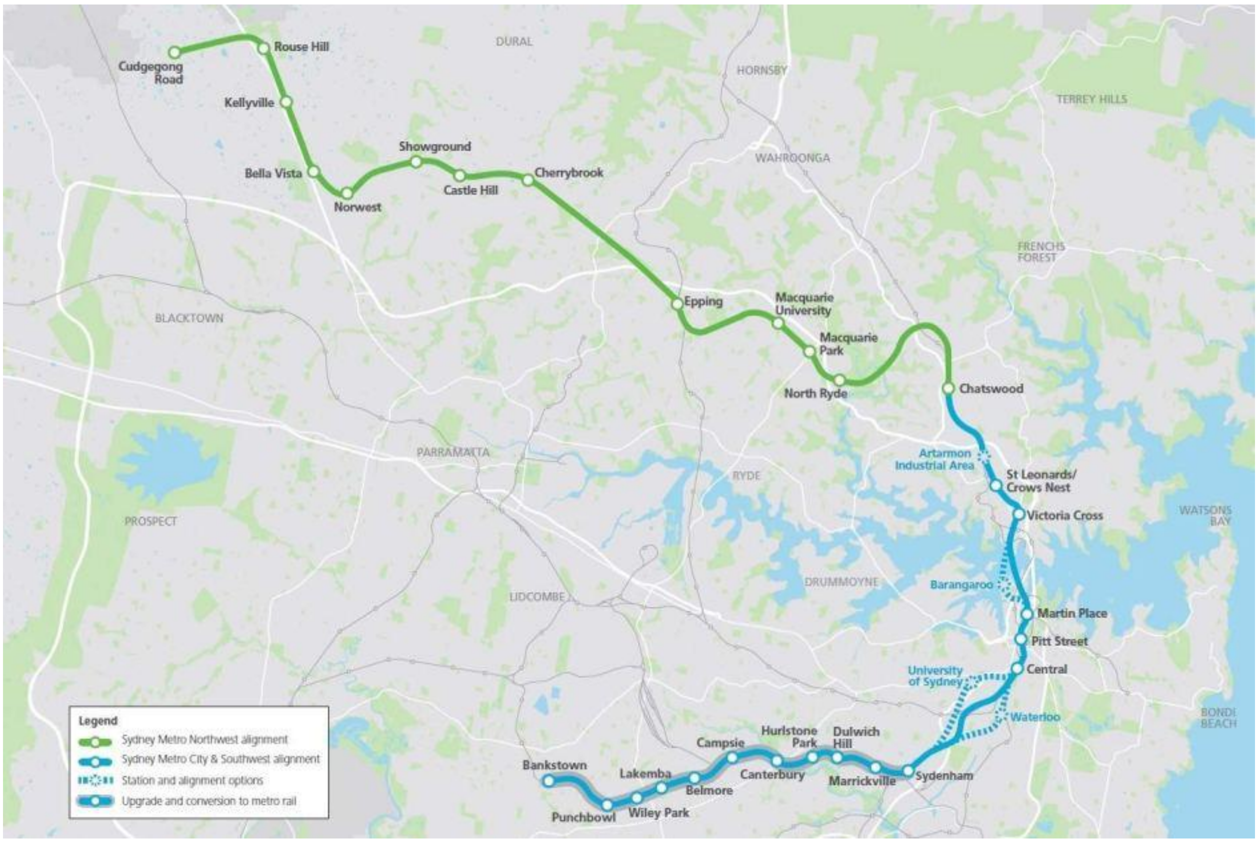


Figure 4.2 Top 40 busiest rail stations (am peak 3.5 hours)
(NSW Bureau of Transport Statistics 2012)

4.2.4 Sydney Metro Rail

The focus of current government rail transit policy is to construct future infrastructure along the lines of 'metro-style' operations. Metro systems typically utilize underground or elevated right-of-way rail alignments, single deck carriages and driverless trains. They typically add greater capacity per rail kilometre than traditional 'shared' rail operations and deliver faster services. The current Northwest project is the first Metro for NSW government investment. The government plans additional Metro operations when this is complete.



Map 4.3 Sydney Northwest Metro Rail map
(Sydney Metro 2012)

The construction of Sydney's Northwest Metro is the largest public transport infrastructure project undertaken in Australia. The project aims to deliver a standalone rail system with 31 metro stations and more than 65 Kilometres of new rail infrastructure. The new rail service operates without timetables, travelling up to 100 kilometres per hour and offering 4-minute intervals between services at peak times. The metro has a target capacity of approximately 40,000 travellers per hour, similar to other metro systems operating worldwide. Sydney's current urban system capacity reliably carries 24,000 people an hour per line. With other improvements to signalling and infrastructure on the existing network, authorities expect to increase the overall capacity of train services entering the CBD from 120 services an hour at present to a maximum of 200 in 2024. This translates to an increase in capacity of up to 60% across the metropolitan network (Sydney Metro 2018a).

Construction of the Sydney Metro takes place in two stages. The first stage initially connects 8 new rail stations in the new northwest growth area with Epping on the existing Northern Line. The

Metro then incorporates the recently completed Epping-Chatswood rail link, which has been modified to accommodate rapid transit operations. The second stage extends the Sydney Northwest Metro under Sydney Harbour through the CBD and beyond to the southwest districts. This stage will provide an additional 7 underground stations in the Global City precinct (on both sides of the harbour) and convert an existing 10 stations between the CBD and Bankstown to accommodate Metro operations. Stage 1 was completed in 2019 and Stage 2 is due for completion in 2024.

Following completion of Northwest/Southwest Metro system the NSW government aims to construct a second Metro rail line linking Parramatta in the west and the Sydney CBD. The Sydney Metro West project will address the transport needs of Sydney's fastest growing corridor, which is expected to house an additional 420,000 residents within the next 20 years (Sydney Metro 2018b). Sydney Metro West will effectively double the rail capacity of the Parramatta/Sydney corridor. The NSW Government has yet to indicate station locations although four key precincts have been identified as non-negotiable recipients of new rail access in the Metro West corridor. These include, Parramatta, where the number of jobs is expected to double and reach 100,000 by 2040; Sydney Olympic Park, where an additional 34,000 jobs and more than 23,000 new residents will be located by 2030; The Bays Precinct, which has been designated as Sydney's new innovation hub and a centre for new commercial and residential development; and the Sydney CBD where Metro West will interlink with the Northwest/Southwest Metro. Sydney Metro West will also integrate with long-term transport planning for Western Sydney including the future Western Sydney Airport. The new railway is expected to be built largely underground and begin operations in the second half of the 2020s.

Map 4.4 Sydney West Metro Rail map
(Sydney Metro 2016)

4.2.5 Sydney WestConnex and NorthConnnex

Chief competitor of the rail system is the motorway network. Road systems in general account for approximately 80% of commuter distance travelled (see Figure 4.3 Mode share of trips by Sydney residents on an average weekday). However, Sydney's chronic traffic congestion has placed motorway development high on the list of government priorities. The latest and most controversial addition to Sydney's motorway infrastructure is the WestConnex project. When completed, the new 33km motorway will provide important support for Sydney's long-term economic and population growth (Map 4.5). WestConnex involves widening the existing M4 motorway between Parramatta; doubling the capacity on the M5 East corridor; and building new underground extensions to enable convergence of the M4–M5 Link tunnel routes. The motorway will effectively create a western bypass of the Sydney CBD. It will also enable connections to a new Western Harbour Tunnel, connect the M4 to Sydney Airport and Port Botany, and provide future connections for the proposed F6 Motorway extension (Map 4.5).

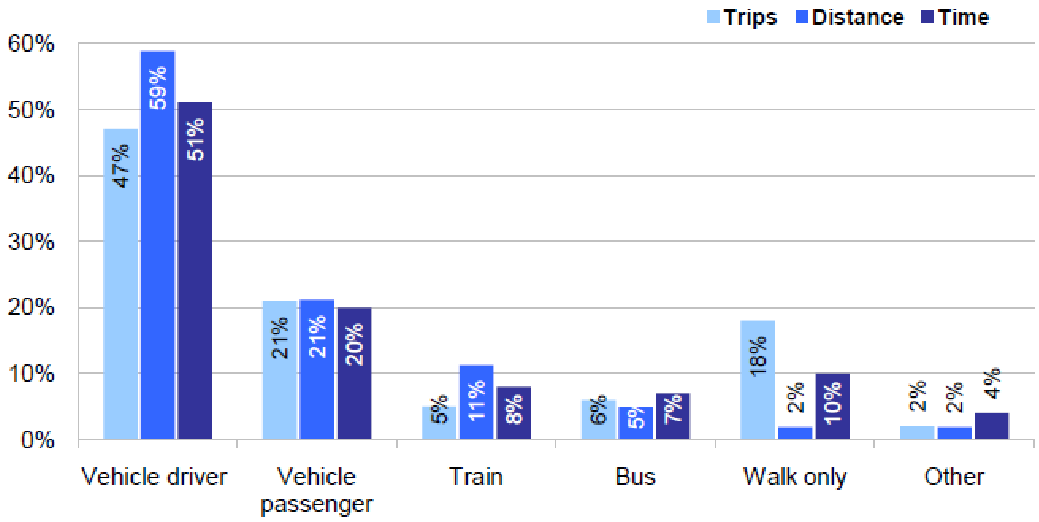


Figure 4.3 Mode share of trips by Sydney residents on an average weekday (NSW Bureau of Transport Statistics 2012)

The new motorway will enhance capacity for through traffic in Sydney, which has been one of the main issues suggested as inhibiting the city's economic growth. In particular, it is designed to reduce the strain on local roads, remove serious city bottlenecks, relieve congestion for road users and improve safety of travel across the city. The motorway will bypass up to 52 sets of traffic signals throughout the metropolitan area to significantly improve travel times and potentially reduce emissions. WestConnex is expected to open for use in the mid-2020s.

Map 4.5 Sydney WestConnex map
(WestConnex 2016)

NorthConnex is a 9-kilometre underground motorway currently under construction in Sydney's northern region. NorthConnex will link the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at West Pennant Hills. When complete in 2020 the motorway will link Sydney's north to the Orbital Motorway and enable travel from Newcastle (M1) to Melbourne without traffic lights. NorthConnex is expected to boost the state and national economies by providing more reliable journeys for commuters and shorter travel times for the movement of freight. Together, the new motorway and rail projects lay the foundation for a future effective transport system and perpetuate the balance offered by the two alternative transport modes.

4.3 Metropolitan centres policy and sub-centre classification

This research is designed to estimate the effect of rail accessibility on property prices and residential sorting in the Sydney metropolitan area. This requires an examination of neighbourhoods nearby rail access points. Ideally, the modelling should explore the effects of rail at a range of sub-centres differentiated by economic importance. This will help to isolate the effect of rail on residential sorting as opposed to the influence of other attractors. Therefore, it is important to consider how centres are defined according to the size and extent of their attributes.

4.3.1 Centres policy

Centres policy has been a feature of Sydney's urban planning strategies for some decades. Planning authorities have long acknowledged the many benefits of concentrating activities in sub-centres. These include, improved access to employment and accessibility to retail, health, education, entertainment, leisure and cultural, community and personal facilities. From a commercial perspective, the objective of the sub-centres policy is to encourage collaboration, competition and innovation amongst businesses, which emerge from commercial clustering. In addition, centres policy encourages greater utilization of existing public infrastructure and promotes sustainable transport.

4.3.2 Sub-centre classification

Sydney's metropolitan strategic centres classifications, provided by the Department of Planning and Infrastructure (2013), offers a suitable means to distinguish urban sub-centres according to the size and variety of their location attributes. Classifications include, Global Sydney incorporating the CBD and North Sydney as the city's dominant employment zone, regional cities, specialised centres, major centres, town centres, villages and neighbourhoods. Brief descriptions of these are contained in Table 4.3 below, with full details provided in Appendix A.

Classification	**Brief description**
Global Sydney	Encompassing the metropolitan area's unique CBD, incorporating North Sydney, as the dominant employment zone and primary base for nationally and internationally significant businesses, entertainment and cultural facilities.
Regional Cities	Focus on cultural, shopping and business services; these centres employ at least 15,000 people and typically have capacity for 35,000 to 50,000 dwellings.
Specialised Centres	Zones of high value economic activity.
Major Centres	Provide a minimum of 8,000 jobs and capacity for 9,000 to 28,000 dwellings, with large shopping centres, civic and recreation facilities, and are generally centred around public transport nodes.
Town Centres	Typically comprise 50 or more commercial premises, usually with supermarkets, high street specialist shops, restaurants, schools and community facilities. These centres are mainly residential locations with capacities of around 9,500 dwellings.
Villages	Capacity for approximately 5,500 dwellings.
Neighbourhoods	Capacity for approximately 500 dwellings.

Table 4.3 Sydney's metropolitan strategic and other centre classifications
(NSW Department of Planning and Infrastructure 2013)

The categories referred to as Global, Regional, Specialized and Major are collectively known as Strategic Centres. These centres play a vital role in shaping the future of the city's subregions. They are the focus of economic development aimed at alleviating the redistricted commercial land use in the CBD and promote decentralization of employment opportunities. Collectively, more 770,000 jobs are currently located at existing Strategic Centres (NSW Department of Planning 2007).

Smaller local centres shown in Table 4.3 are categorized as Town, Village and Neighbourhood Centres. These centres usually serve pockets of communities throughout the subregions and are typically based along busy thoroughfares. They generally comprise small strips or group of shops servicing residents' daily needs. Rail infrastructure at town or village locations typically act as a catalyst for retail and commercial development around the station by establishing a pedestrian catchment area.

4.4 Rationale for selection of impact locations

The present study investigates the effect of rail on residential sorting at a range of different urban sub-centre types. The inclusion of a broad spectrum of sub-centre locations enables sufficient variation in the data to accommodate spatial heterogeneity. However, some location classifications are more suitable than others as research subjects. For example, areas within Global Sydney offer little opportunity to isolate the effects of rail accessibility due to the proximity of different transport alternatives. On the other hand, Regional, Major and Town Centres generally offer distinctive communities focused on a single transport hub and are more likely to provide evidence of rail induced property value uplift and residential sorting. Specialized Centres are typically contrived communities engineered with attractors that are generally predetermined as a consequence of developing specialist commercial, educational and/or health related activities. Hence, Specialized Centres are unlikely to reflect natural residential sorting. Small Village and Neighbourhoods Centres usually offer an insufficient variety of residential structural types to enable suitable diagnostics for this research. In this study, Global Sydney, Specialized Centres and those ranked below Town Centres are excluded from the analytical process.

The study investigates twenty-three locations interspersed throughout the Sydney metropolitan area. Each location differs in the size and importance of their commercial district. Observations for all three Regional Centres, as classified by the New South Wales Department of Planning and Infrastructure, are included. Similarly, each of the nine Major Centres with rail access have been included. There are insufficient Major Centres without rail access to provide meaningful control data and these have been excluded from the study. For this study, Regional and Major Centres are grouped as one because of their similarities regarding economic importance.

The Sydney metropolitan area has numerous Town Centres, but only some qualify as suitable for the purpose of this study. In this study, eleven such locations have been selected, which is approximately the same number of combined Regional/Major Centres. Selection of Town Centres is based on three criteria. First, as far as possible, they are distributed evenly over the metropolitan area; second, they offer access to rail transit with direct connection to trunk routes; and third, they provide scope to analyse residential sorting over a broad area, which is unaffected by the influence of other nearby rail stations.[11]

4.5 Functional profile of the subject locations

This section briefly summaries the functional and residential dwelling characteristics of each location included in the present research. The locations are categorized as Regional, Major and Town Centres according to classifications provided by Department of Planning and Infrastructure.

4.5.1 Regional Centres

Regional cities play an important role in creating a series of connected sub-cities within the greater metropolitan area. These centres are designed to offer a full range of business, government, cultural, entertainment and recreational activities. They are also large employment centres, with major health and tertiary education facilities. Regional cities are expected to develop a system of mixed-use villages nearby to provide space for supporting activities and residential communities. The Regional Centre is a long-term aspirational concept of metropolitan planning, which includes the objective that all greater Sydney residents live within 30 minutes travel time of these centres.

Parramatta (4 lines, rail station opened 1855)

The Sydney Metropolitan Strategy identifies Parramatta as Sydney's most important Regional Centre. Parramatta is located 24 kilometres west of the CBD and features a large commercial hub with a full range of business, government, retail, cultural, entertainment and recreational activities. In 2011 the city of Parramatta provided approximately 46,500 local jobs and is expected to accommodate an additional 27,500 jobs by 2031.

[11] See further discussion in Chapter 3.

State and local authorities place considerable emphasis on Parramatta as an alternative CBD and a major source of commercial and government services. The Cities Taskforce, comprising representatives from State and Council bodies, has an ambitious Civic Improvement Plan to deliver a significantly greater volume of space dedicated to commercial, retail and residential use, together with increased leisure, entertainment, and community services NSW Department of Planning 2007. The NSW Government has already invested $330 million in the Parramatta Justice Precinct within the City Centre and has established several administrative offices in the area. The federal and state governments have also collaborated to expand the University of Western Sydney, which is now the focus for future local strategic planning.

Parramatta’s transport interchange is centrally located on the main east/west railway line, which links Parramatta to Olympic Park and Sydney CBD in the east and Blacktown, Penrith and the Blue Mountains in the west. The interchange also connects the T5 north-south rail line between Schofields, Liverpool and Campbelltown. This transport system makes Parramatta one of the most easily accessible centres in the greater metropolitan region and therefore a desirable residential centre. There has been a noticeable increase in residential densification surrounding the transport interchange. Building heights have reached 55 floors in the area and there are plans for a number of residential and mixed-use buildings ranging between 60 and 90 floors.

Penrith (2 lines, rail station opened 1863)

As a Regional Centre, Penrith is a major focus for public investment, which is designed to ensure its role as an employment hub and service centre for Western and North Western Sydney. Penrith occupies a strategic position at Sydney’s western gateway and has evolved as a distinctive commercial centre with a broad range of retail, community and social facilities. The centre also acts as an important cultural and civic hub for the region.

Penrith is a major focus for new housing. Subregional strategies set targets of approximately 50% increase in jobs (by 2031), which is expected to drive greater levels of residential growth. There are a number of council and government owned sites close to the city centre and the railway station, which are earmarked for residential redevelopment. These include a 50-hectare defence site, adjacent to the rail station, planned for 800 dwellings and 2,000 residents. Opportunities also exist for residential development in other fringe areas such as those surrounding the Nepean River, Panthers entertainment complex and the Nepean Hospital.

Liverpool (3 lines, rail station opened 1856)

The regional city of Liverpool is located in the South West Subregion of the Sydney metropolitan area. In 2011, Liverpool provided approximately 14,054 jobs and has an employment capacity target of 30,000 by 2031. Health is the largest industry in the Liverpool district. Liverpool Hospital is the principal referral unit for the Sydney South West Area Health Service and a major teaching and research facility connected to the University of NSW. Other important commercial functions involve retail, property and business services, including information technology, legal services, accountancy, management and finance.

Liverpool Station is a major transport hub in the South West Subregion, servicing the T3 Bankstown, T2 South/Inner West and T5 Cumberland Rail Lines. The transport interchange is also a focus for the local region bus network. Commercial development is largely concentrated around the public transport interchange and major retail facilities are located nearby at Macquarie Street Mall and Westfield Shopping Centre. Liverpool Hospital is also close to the rail station and transport interchange.

There is limited variation in the type of residential housing found in the Liverpool Centre district. 'Shop–top' housing is common within the city centre, while two and three storey flat complexes tend to dominate locations to the north, west and south of the retail and commercial core. Most new residential development occurs on the periphery of the city centre, particularly in the northern precinct.

4.5.2 Major Centres

Major centres generally feature extensive shopping facilities and business services primarily serving the immediate subregion population. A Major Centre usually has a full-scale shopping mall, council offices medium to high-rise commercial and residential buildings located within a one-kilometre radius of its core. It also has central community facilities and a minimum of 8,000 local jobs. A Major Centre typically provides employment close to public transport to minimize the negative environmental impact of private vehicle use.

Bankstown (1 line, rail station opened 1909)

Bankstown is classified as a Major Centre satisfying the criteria of significant economic importance, mixed functional activity and comprehensively serviced by public transport. It is the key business, shopping and administrative centre for the South district and a considerable portion of the neighbouring southern areas of the metropolitan West Central district. Bankstown is situated on the T3 Bankstown railway line, which links the Sydney CBD 15 kilometres to the east and the regional city of Liverpool to the west. It is also the end of line for Sydney's new Metro Rail development due to be completed in the mid-2020s.

The majority of Bankstown's commercial and retail activity is clustered nearby the rail station. In 2011 Bankstown supported 16,575 local jobs and this is forecast to grow modestly to approximately 20,200 by 2031. The city's current population of 32,500 is expected to grow by 10,000 residents over the same period. Residents are generally housed in low, medium and high-rise building at the city core, and beyond this area in low rise, townhouses and separate-family dwellings.

Blacktown (3 lines, rail station opened 1860)

Blacktown has developed as an important retail destination and there is growing investment in health and education facilities at the centre. The city is located at the junction of the T1 Main Western, T5 Richmond Branch Rail Lines and the NSW TrainLink Intercity Blue Mountains Line. The Richmond Rail Line links Blacktown to North West growth region. It is also served by the North West Transitway and has good access to the Orbital Motorway.

The centre lacks a strong commercial office sector, due to its proximity to Norwest, Parramatta and other major commercial centres. Nevertheless, Blacktown local government area is one of the fastest-growing regions in NSW and future growth is expected. Local community authorities have considered the prospect of Blacktown emerging as a second regional city for the north-west metropolitan region. However, this is severely constrained by a lack of potential for new office space. A larger commercial core would also need to be supported by greater residential densification at the city centre. Recently, the local council indicated its willingness to sanction high-rise residential buildings in excess of 20 floors at the city's core to enable greater commercial capacity in the district.

Bondi Junction (2 lines, rail station opened 1979)

Bondi Junction is designated a Major Centre for the metropolitan east region and is regarded as a location for substantial future job growth, primarily in retail. The centre already has a broad retail reach covering Waverley, Woollahra and parts of the Randwick LGA. Office space has lagged growth in retail. Recent cycles of residential and retail expansion have resulted in limited opportunities to expand large-scale A-grade office development. However, there already exists a strong presence of professionals such as lawyers, accountants, architects and health care workers, with clientele predominantly from the local surrounding suburbs.

Bondi Junction is a desirable and expensive location for home-seekers. Apart from its extensive retail complex it is one the few locations east of the city with access to rail transport. It is also ideally situated between the CBD and the coast. In the local context, this means proximity to two major attractors, both having a significant effect on property values. Bondi Junction has an abundance of high-rise residential housing, together with a mixture of low to medium rise, terrace, townhouse, villa and separate family dwellings.

Burwood (4 lines, rail station opened 1892)

Burwood is the dominant centre for retail, commercial, administrative and civic services in the inner-west and has a strategic role in servicing a large resident population. Burwood has been identified as one of the primary growth areas for job and residential dwellings. In 2011, around 12,200 people worked in the Burwood area and this is expected to grow to approximately 15,400 workers by 2031. The commercial centre is concentrated around the rail station and the main business strip extends northwards along Burwood Road. Located off Burwood Road, just north of the station, is Westfield shopping mall, which is one of the subregion’s primary retail outlets.

The centre has become an important hub for commercial activities servicing the Burwood local government area and broader inner-west region. It is also a major centre for professional services associated with the local courts and a wide range of small medical practices that are concentrated nearby the rail station. These sectors continue to lead demand for future office space requirements. Burwood is expected to develop further as a Major Centre due to expansion of civic, commercial and retail activities and continued growth in specialized legal and medical services. There are plans for residential densification with recent approval of four apartment buildings ranging from 20 to 42 levels. The new buildings will be constructed in the heart of Burwood’s CBD close to the rail station.

Campbelltown (4 lines, rail station opened 1858)

Campbelltown combines with nearby Macarthur to form the local area Major Centre. Both centres have different but complementary functions. Campbelltown is a major business and cultural centre, with a mix of commercial, cultural, retail and civic activities, while Macarthur provides the main destination for retail, tertiary education and health services in the area.

Campbelltown and Macarthur are located on the T8 South Rail Line and in the F5/M5 motorway corridor. Both locations offer bus interchanges adjacent to their train stations. This has stimulated pedestrian traffic along with commercial and residential development in the areas immediately surrounding these facilities. Interestingly, the Macarthur precinct has evolved with relatively lower residential density, while Campbelltown has emerged as the local focus of population growth.

Chatswood (4 lines, rail station opened 1890)

Chatswood constitutes Sydney's largest Major Centre and represents a key retail, residential, cultural and employment location. The commercial precinct offers approximately 300,000m^2 of office space, with multi-story office and residential tower development immediately adjacent to Chatswood rail station. The centre also has approximately 190,000m^2 of retail space, comprising large shopping malls and a number of small retail centres, arcades, shopping strips and live theatre facilities (NSW Department of Planning and Infrastructure 2013). Chatswood rail station is a major rail hub servicing the T1 North Shore Line T1 Northern Line, T1 Western line and the Central Coast and Newcastle Line.

Hurstville (2 lines, rail station opened 1884)

With over 150,000m^2 of retail floor space Hurstville is considered to be the dominant retail centre for southern Sydney. However, Hurstville has also experienced strong residential growth leading to significant increased housing density surrounding the rail station. As a result, there is competing demand to ensure sufficient supply of future office space and to maintain the location's role as a major commercial centre. The area's residential and commercial attraction is enhanced by accessibility to efficient public transport, which includes multi-line rail access and a bus interchange adjacent to the train station.

Hornsby (3 lines, rail station opened 1894)

Hornsby is considered a 'mixed-use' Major Centre and an important public transport hub. Hornsby connects Sydney's public transport system to the Central Coast and Lower Hunter. In 2011, there were approximately 15,000 jobs located in Hornsby with most employment engaged in retail, education and service industries. The commercial precinct has an estimated 150,000 m^2 of commercial/retail space, with the Westfield shopping complex providing 92,000 m^2 or 60% of the total. Hornsby is a major retail destination for the Sydney northern region with its large shopping mall and adjoining smaller retail centres, arcades and shopping strips. An impediment to future development is the rail line divides Hornsby's commercial district. This has resulted in fragmentation of the centre into a series of precincts each with their own particular function.

Hornsby is a key interchange for travellers from the Central Coast and Lower Hunter heading to various employment destinations including Global Sydney and Parramatta. In the future, this location will be further enhanced by the new NorthConnex motorway, which links Hornsby to the Sydney Orbital and ultimately the CBD. Hornsby Council and the Department of Planning have worked together in progressing the Hornsby Shire LEP 1994 (Parliament of NSW 2006). The aim is to encourage employment-generating development in the commercial/retail core and increase residential and commercial density. Various high-density housing developments adjacent to the city centre are evidence of continued demand for close proximity to commercial development and the transport node.

Kogarah (1 line, rail station opened 1884)

Kogarah has approximately 43,000 m^2 of office space and hosts some major institutions such as St George Bank head office, St George Public and Private Hospitals and a TAFE College. Despite Major Centre status Kogarah's retail component is a relatively small. Shopping is limited to 'high street' strips as nearby Rockdale Plaza caters for much of the area's retail demand.

In 2011, Kogarah supported approximately 11,608 local jobs and this is expected to grow to more than 15,000 by 2030. The traditional main-street and public domain areas are considered vibrant places for residents, pedestrians and workers during the day and evening. Kogarah is often thought of as an exemplar for urban liveable design.

4.5.3 Town Centres

Town Centres typically focus on retail, community and medical facilities, and schools. These centres generally contain more than 50 outlets for retail, commercial and public services with one or two supermarkets and occasionally a small shopping mall. The local commercial complex is usually contained within a radius of 800 metres. Town Centres accommodate between 4,500 and 9,500 dwellings and feature medium and high-density housing mixed within the commercial centre. These centres are usually more residential in origin and less important as employment destinations compared with Major Centres.

Ashfield (1 line, rail station opened 1855)

Ashfield is considered a successful mixed-use Town Centre. Its commercial activity is primarily located along Liverpool Road south of the rail station. The locality supports 7,200 jobs and a workforce of nearly 12,000. There is high-density residential development within the centre core and on the fringes of the centre. The T2 Inner West and T1 Western Lines service the centre and there is a bus interchange nearby the station.

Chester Hill (1 line, rail station opened 1924)

Chester Hill is located 25 kilometres west of the Sydney CBD and is part of the Central West District. The town has a small commercial business district and retail complex located on the north side of the rail station. Low-rise residential unit complexes surround the commercial core. In 2011, the area supported approximately 6,600 jobs and had a local workforce of just 4,700. Daily movement of population flowing into and out of the centre rely on both train and car travel.

Epping (3 lines, rail station opened 1900)

Epping has rail access to the CBD on both the T1 Northern and Central Coast /Newcastle Lines. In 2009 an additional underground platform was opened to service the Epping/Chatswood rail link. This link provides Epping residents with cross-city access to the North Shore line and easy access to the commercial, educational and retail facilities at nearby Macquarie Park. Epping has a commercial/retail floor space of approximately 46,000m^2, with retail services comprising 2,400m^2 (NSW Department of Planning and Infrastructure 2013). The residential areas surrounding the train station comprise a small number of high-rise residential unit buildings, a large number of low-rise unit structures and other separate-family housing. In 2011 the area supported 8,300 jobs and a substantial workforce of 13,300. This imbalance is reflected in the Epping's considerable rail patronage.

Gordon (2 lines, rail station opened 1890)

Gordon is the largest centre in the Ku–ring–gai district and is located approximately 14 km north of the Sydney CBD and 7 km and 6 km from the Major Centres of Hornsby and Chatswood, respectively. Gordon features a 'high street' or 'strip' retail structure with arcades and malls leading from the Pacific Highway. A mix of medium density residential units and separate-family houses characterize the surrounding area. There is approximately 3,000 m^2 of office space and 17,000 m^2 of retail space in the centre supporting around 4,600 jobs. The centre is located close to Gordon Station, which has a high level of commuter patronage (ranked 30).

Local Ku–ring–gai council encourages increased residential densities and commercial diversification in the Gordon town centre and the surrounding villages of St Ives, Turramurra, Pymble, Lindfield and Roseville. Each of these local centres has good access to public transport, retail services and community facilities. The council has in place a strategy, which supports residential densification and encourages mixed land use to accommodate expected shifting demographics in the region as well as increased population.

Granville (4 lines, rail station opened 1860)

Granville is an important juncture of four rail lines comprising the T1 North Shore, T1 Western and Blue Mountains services and the T2 Inner West and South service. The centre features a mixture of commercial, industrial and residential developments focusing on Granville station and Parramatta Road. The location is dominated by separate dwelling weatherboard, fibro or unrendered brick residential buildings located on 500 to 600 m^2 blocks. Apartment blocks are typically 3 to 4 stories and are becoming increasingly common in areas with close proximity to the rail station. In 2011, Granville supported around 12,000 jobs and had a local workforce of 11,500 people. Yet despite its function as a large employment centre Granville does not constitute a Major Centre.

Katoomba (1 line, rail station opened 1874)

Katoomba is the most westerly town in the research area located 110 km west of Sydney CBD. The town is situated on the main T1 Western Line and provides one of the major gateways to the Blue Mountains tourist industry. The town supports 4,200 jobs, largely contained within the Katoomba Street commercial and retail strip. The centre features a mixture of low-density unit housing and separate-family dwellings.

Lidcombe (6 lines, rail station opened 1858)

Lidcombe is located 18 km west of the Sydney CBD. Lidcombe rail station is an important rail junction servicing the T1 Northern, T1 Western and Blue Mountains, T2 Inner Western and South, T3 Bankstown, and T7 Olympic Park Lines. Despite the importance of Lidcombe as a transit hub competing major centres at Parramatta and Bankstown have stifled the centre's retail development. Consequently, local Lidcombe shopping facilities have remained small. To some extent, the constraints on retail growth have been offset by businesses catering for the diverse ethnic mix of the local community. Residential housing in the area is characterised by low-density unit blocks and separate dwellings.

Richmond (1 line, rail station opened 1864)

Richmond Town Centre is located south of the Hawkesbury River at the terminus of the T1 and T5 Richmond branch lines. Commercial and residential development around Richmond centre is significantly constrained due to the potential for flooding in the area and likely to require considerable investment to rectify the problem. However, there is a possibility of additional residential development at North Richmond, which raises the possibility of further growth at the Richmond centre. Residential building types mainly comprise small complex flats or separate-family housing.

St Marys (1 line, rail station opened 1862)

St Marys is an important Town Centre serving the eastern sector of the Penrith local government area. St Marys has several stand-alone shopping complexes located on the periphery of the centre, while office space is mostly confined to first floor level above retail shops. The town's commercial role is generally considered secondary to its retail function.

St Marys' development has struggled in recent years in the face of competition from larger centres such as Penrith, Blacktown and Mt Druitt. The town has also suffered from a trend in the polarization of retailing between large 'destination' centres and smaller convenience centres, as it does not fit comfortably in either of these categories. St Marys Town Centre Strategy nominates several key challenges such as improving pedestrian links and diversifying land use beyond the current dominance of retailing. Redevelopment opportunities in surrounding residential areas are encouraged as an opportunity to catalyse revitalization of the centre.

Strathfield (6 lines, rail station opened 1922)

Strathfield Town Centre provides a distinct but complementary role in relation to the nearby Burwood Major Centre. Strathfield specializes in retail services, while the bulk of commercial and health services are located at neighbouring Burwood. Strathfield has recently become more diverse and lively following dramatic growth in residential development, which is partly attributable to the growing importance of its central position in relation to rail infrastructure. Strathfield has the ninth largest station by patronage (Figure 4.2) and is serviced by six lines including the T1 North Shore and Northern lines, T2 Western and Inner West lines, T1 Blue Mountains line and the T1 Central Coast/Newcastle line. The centre also offers a major bus interchange feeding passengers to the rail station from the surrounding region. Strathfield's residential properties include a mixture of low and high-rise unit buildings as well as separate-family houses.

Sutherland (2 lines, rail station opened 1885)

Sutherland is located approximately 30 km south of the Sydney CBD and is the administrative centre for the Sutherland Shire local government area. The Town Centre hosts a general-purpose entertainment centre, educational and sporting facilities. Sutherland's commercial/retail town centre is situated predominantly to the east of the rail line. Sutherland station services both the T4 Cronulla/Illawarra and South Coast lines.

There is a predominance of high and low-rise unit housing immediately surrounding the town centre tending to separate family dwellings beyond these areas. A large cemetery to the west of the town and parks to the north, south and east severely restricts the prospect of further residential growth. The area supports 4,900 jobs and has a potential workforce of 7,105 people.

4.6 Household characteristics by district and centre type

The descriptive statistics in Table 4.4 show the spatial variation of structural and demographic characteristics by metropolitan district. This is followed by Table 4.5 with descriptive statistics for Major/Regional and Town Centres. These estimates are based on the study's 11,912 transaction observations at the twenty-three locations targeted in this study and contain data from the observations' respective SA1s. These tables provide important contextual information leading to an investigation of rail transit effects.

District analysis

	Central		North		South		West Central		West		South West	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
ADJPRICE	546,741	207,548	612,383	279,300	464,243	101,712	360,230	87,958	273,975	59,303	284,151	67,650
BED	1.99	0.63	2.07	0.70	2.16	0.57	2.27	0.60	2.46	0.61	2.25	0.59
BATH	1.45	0.53	1.55	0.54	1.41	0.52	1.48	0.52	1.37	0.51	1.35	0.51
CAR	1.11	0.50	1.16	0.49	1.15	0.46	1.18	0.51	1.19	0.47	1.21	0.47
LOT	61.78	68.25	92.00	92.1	37.59	43.35	50.57	57.27	20.62	27.77	38.92	36.11
BLDGAGE	20.20	17.37	14.94	15.61	18.86	16.37	11.68	10.59	14.27	12.07	17.40	13.48
ASSAULT	990	479	474	153	701	81	1,373	589	1,800	418	1,400	291
ROBBERY	214	83	65	26	143	64	242	148	145	48	174	12
BRKENTR	622	102	399	46	442	103	708	116	645	107	800	125
MVTHFT	311	94	119	27	294	45	575	192	605	118	610	8
SEMPLOY	9,747	2,494	17,143	8,900	10,406	2,758	23,602	13,374	14,262	6,442	15,170	1,390
SPOPDN	5,749	1,487	2,977	942	4,779	1,248	3,656	927	1,029	269	2,687	1,414
PcARP	84	18	88	23	85	25	79	28	69	28	71	30
Pc2KPLUS	6.98	5.52	11.33	4.76	4.43	2.28	2.63	2.30	2.15	1.26	2.15	1.55
PcUNIQL	31.73	5.13	36.59	5.22	26.90	8.60	22.32	10.53	9.83	3.88	11.75	3.65
PcPROF	15.14	3.19	18.28	4.12	13.04	3.84	9.76	4.57	6.76	3.16	7.02	3.30
PcUEMP	5.06	1.93	4.70	2.02	4.61	1.85	5.99	2.06	4.89	1.87	5.09	1.94
AVAGE	36.23	5.43	35.19	3.66	35.77	4.82	32.41	4.14	38.54	7.74	33.95	3.95
PcAUSB	33.21	15.06	34.96	14.19	41.41	21.64	34.84	13.36	71.99	8.35	48.93	19.56
PcFAMDEP	21.47	8.06	27.30	7.97	25.89	7.76	34.17	9.09	22.97	7.89	30.58	10.14
PcRENTER	54.51	12.69	49.74	15.07	47.27	13.56	53.00	16.52	53.62	18.13	53.84	17.19
AVMVOWN	0.94	0.23	1.02	0.33	1.08	0.26	1.17	0.27	1.19	0.31	1.21	0.29

Table 4.4 Descriptive statistics: variables by district

Districts differ primarily due to their proximity to the CBD and coast.[12] These are considered factors that have a considerable influence on home-seeker location choice. For example, Central,

[12] See Map 3.1.

North and South districts are thought to offer more desirable locations than districts farther west due to their relatively easier access to the CBD and the coastal or harbour environments. Proximity to the coast is particularly desirable given its aesthetic appeal and more moderate and pleasant climatic conditions. Although less desirable in terms of ambience, the West Central district has the advantage that it is the geographic centre of the Sydney metropolitan region. This district focuses on Parramatta, which is earmarked for development as Sydney's 'alternative' CBD. The remaining outer districts, comprising West and South West, are largely developing areas with a focus on more affordable single-family detached housing.

Table 4.4 shows there are variations in some household characteristics across the Sydney metropolitan districts. Most pronounced are the differences in property values (*ADJPRICE*). The mean prices of the North district, with its proximity and aesthetic attraction, are highest amongst the districts. Central, South and Central West follow this, while the lowest housing prices are located in the West and South West districts.

Structural characteristics show mixed results. While *BED*, *BATH* and *CAR* reveal similar means and standard deviations, other factors such as *LOT* and *BLDGAGE* indicate considerable variation. Lot numbers per complex are on average higher in the North and Central districts, which probably reflects higher land value in these districts. Building age is greatest in the Central district, which may be due to the fact that this contains areas of earliest settlement.

Crime statistics reveal some variation across districts. The incidence of *ASSAULT*, *MVTHFT* and *BRKENTR* loosely correspond to house price averages. On the other hand, the pattern of *ROBBERY* is less obvious in relation to property prices. The latter variable is perhaps more aligned with the level of unemployment in the region.

Other community characteristics, such as *SEMPLOY*, *SPOPDN* and *PcARP*, also show mixed results. *SEMPLOY* is likely to be influenced by the particular data collected. For example, the concentration of suburb employment is greatest in the Central West district, which contains the largest Regional Centre in the data set. Similarly, other districts differ according to the mix of commercial centre types. *SPOPDN* is based on the range of SA1s included in the data set and show no conclusive pattern. This is consistent with other metropolitan areas that have broadly even population density and interrupted only by the effect of intermittent suburban commercial centres. *PcARP* loosely follows the pattern of lot size, which as explained, appears to be related to property values.

Some demographic variables show distinctive variations associated with district boundaries. For example, *Pc2KPLUS*, *PcUNIQL* and *PcPROF* are highest in the eastern districts that are closer to the CBD and coast. This broadly follows the pattern of housing prices. On the other hand, *PcUEMP*, *AVAGE* and *PcRENTER* are basically similar across the metropolitan area. Of the remaining demographic characteristics, there appears to be a slight tendency for a higher *PcAUSB* in the western districts, while there is no obvious pattern associated with *PcFAMDEP*.

Regarding the neighbourhood characteristic *AVMVOWN*, there is some evidence of higher concentration in outer areas. Although the range of motor vehicle ownership is small the mean values appear to indicate relatively higher levels in Central West, West and South West compared to the other districts. This may reflect a greater need for road transport in the outer districts due to the relatively long commute distances and lower concentration of public transport alternatives.

Major/Regional and Town Centres

	Major/Regional Centres		**Town Centres**	
	Mean	**SD**	**Mean**	**SD**
ADJPRICE	456,067	221,853	450,753	150,901
BED	2.16	0.64	2.22	0.63
BATH	1.46	0.53	1.43	0.52
CAR	1.15	0.48	1.20	0.50
LOT	59.90	41.64	39.60	33.29
BLDGAGE	15.26	14.242	17.83	16.20
ASSAULT	1,115	551	889	631
ROBBERY	187	117	124	67
BRKENTR	612	174	524	145
MVTHFT	433	211	291	199
SEMPLOY	18,978	9,583	7,101	1,580
SPOPDN	3,957	1,678	3,297	1,925
PcARP	83.72	25.36	74.14	26.68
Pc2KPLUS	5.11	4.86	5.97	4.96
PcUNIQL	25.14	11.11	26.26	11.97
PcPROF	11.95	5.34	13.74	5.84
PcUEMP	5.28	2.06	4.75	1.91
AVAGE	34.41	5.17	36.52	5.02
PcAUSB	37.96	18.24	47.61	20.70
PcFAMDEP	28.14	9.97	26.12	8.55
PcRENTER	53.04	15.22	48.44	15.90
AVMVOWN	1.06	0.29	1.16	0.31

Table 4.5 Descriptive statistics: variables by type of commercial centre

The results for Major/Regional and Town Centres are again mixed. The most pronounced effects of commercial district size are found in *SEMPLOY*, which is unsurprisingly dominated by Major/Regional Centres. On the other hand, *PcAUSB* and *AVMVOWN* are noticeably higher in Town Centres. Other variations reveal that, on average, crime is higher at Major Centres and, as expected, *PcARP*, *SPOPDN* and *PcRENTER* are also higher in these localities. Employment related factors, such as *Pc2KPLUS*, *PcUNIQL* and *PcPROF* are each slightly higher in Town Centres, while *PcUEMP* has the opposite effect recording a higher average in Major Centres.

The significance of distance to the CBD and coast as well as commercial district size is examined further in Chapters 5 and 6. The objective of these chapters is to explore the effect of proximity to rail access on property prices and demographic characteristics. This analysis controls for the influence of the geographical and locational factors outlined above along with other factors that potentially moderate the influence of rail transit on property prices and demographic structure.

5 Stage 1 Results: Estimation of Proximity Premiums

There is common agreement in the literature that property value is a key determinant of residential location decisions. The purpose of this study is to determine if rail transit stations in Sydney influence property prices and therefore the decision-making processes of home-seekers. There are two inter-related objectives. These objectives are considered in two stages of the study. This chapter deals with Stage 1, which examines the relationship between rail accessibility and housing prices. Chapter 6 examines the possible influence of rail accessibility on residential sorting. The discussion that follows in Chapter 7 explores the relationship between these findings and the implications of the research.

This study employs a multivariate HPM and GWR to estimate the effect of rail accessibility on residential property prices. The HPM is a function of equilibrium prices and characteristics. The estimations represent average values across space and are termed 'global' observations. On the other hand, GWR investigates the individual data that form the global averages. In this case, calculations are termed 'local' observations as they describe the situation at the local level.

Prices used in the modelling process are derived from 11,912 sales transactions in the Sydney region during the 2011 census year, or at most one year either side of focus period. This provides sufficient observations to effectively gauge the relationship between the dependent variable, (price) and a broad range of independent variables. To protect the integrity of the cross-sectional data set, the dependent variable is represented by the adjusted transaction price of residential unit housing indexed to 2011 (*ADJPRICE*).[13]

The study investigates twenty-three locations at mature rail station sites interspersed throughout Sydney. Each location differs in the size and importance of their surrounding commercial districts, which accommodates the principle of multiple nuclei. Concentric circles around each of the rail stations distinguish rail-accessible (*ZONE1*,*2*,*3* and *4*) and non-rail-accessible zones (*ZONE5*), with the latter providing control areas.

5.1 Hedonic Price (global) Model

As discussed, the HPM is calibrated with data equally across the study area and therefore yield global parameter estimates. A wide range of predictive variables associated with housing

[13] See Section 3.2.4

incorporating structural, accessibility and neighbourhood characteristics are included in the model. All predictive variables proposed for inclusion in the model (Section 3.2.3) are theoretically justified. However, in formulating and specifying a suitable model it is necessary to conduct a preliminary investigation of variable independence and to consider an appropriate specification and functional form.

5.1.1 Specifying the model

An investigation of stochastic independence amongst the proposed model variables listed in Chapter 3 reveals that distance to the coast and metropolitan district variables are unsuitable for inclusion in the model. A bivariate correlation matrix identifies significant correlations between these variables, and also with distance to the CBD. Furthermore, Variance Inflation Factor (VIF) diagnostics show the presence of all three factors give rise to potential multicollinearity and that the inclusion of just one amongst them is necessary to reduce all VIF values to acceptable levels. Tests show ln *(CBD)* offers superior model performance and therefore precludes the remaining two factors from the estimation process.

Similarly, multicollinearity is identified amongst the variables representing crime statistics. The same diagnostics used above indicate highly significant correlations between rates of assault, robbery, break and enter and motor vehicle theft. To avoid these issues *ASSAULT* is used in the model as the solitary variable representing crime statistics.

Earlier, we discussed the potential impact of socio-economic indicators on housing prices. Candidates for inclusion in the model are income (*Pc2KPLUS*), the concentration of professionals (*PcPROF*), university qualified (*PcUNIQL*) and the level of unemployment (*PcUEMP*). While preliminary investigation suggests a strong relationship between house prices and the level of income it also highlights the role of the latter as proxy for other socio-economic variables. For example, cross-correlation matrix at the SA1 level reveals a significant relationship between the level of income and concentration of professional households. It also detects a strong relationship between professionals and university qualified. In this case, model performance is enhanced by the inclusion of the income variable and exclusion of variables relating to profession and university qualifications. In addition, tests for the level of household unemployment indicate no significant impact on housing prices. Given the desirability of a parsimonious model, the inclusion of such variables need only apply if they aid interpretation of the model. In this case, the level of SA1 unemployment is eliminated from the model.

5.1.2 The equation

For the purpose of this study the hedonic pricing estimation is derived from the following equation specification:

$$\ln(ADJP) = f(BED, BATH, CAR, VILTH, LUX, FLFLOOR, LV234, LOT, BLDGAGE, BLDGAGE2, ZONE1234, PARKING, LINES, MW123, \ln(CBD), WTRSIDE, ADJPARK, SCHZONE, ASSAULT, Pc2KPLUS, LESS100, MAINRD, SEMPLOY) \quad (5.1)$$

where:

$\ln(ADJP)$	=	Log of adjusted transaction price
BED	=	Number of bedrooms
$BATH$	=	Number of bathrooms
CAR	=	Number of car spaces
$VILTH$	=	Villa/townhouse/terrace properties*
LUX	=	Luxury apartment complex*
$FLFLOOR$	=	Full floor unit*
$LV2$	=	4th to 9th level*
$LV3$	=	10th to 19th level*
$LV4$	=	Level 20 plus*
LOT	=	Total lot size of strata plan
$BLDGAGE$	=	Building age
$BLDGAGE2$	=	Building age squared
$ZONE1$	=	up to 200 mtrs from station*
$ZONE2$	=	201 - 600 mtrs from station*
$ZONE3$	=	601 - 1000 mtrs from station*
$ZONE4$	=	1001 - 2000 mtrs from station*
$PARKING$	=	Rail station parking*
$LINES$	=	Number of rail lines serviced by local train station
$MW1$	=	up to 500 mtrs from motorway*
$MW2$	=	501 - 1000 mtrs from motorway*
$MW3$	=	1001 - 2001 mtrs from motorway*
$\ln(CBD)$	=	Log of distance to CBD
$WTRSIDE$	=	Waterside district*
$ADJPARK$	=	Adjacent to a park*
$SCHZONE$	=	Within catchment area of suburb’s best performing school*
$ASSAULT$	=	Rate of assault at SA1 level

Pc2KPLUS	=	Percentage of population earning greater than $2000 per week at SA1 level
LESS100	=	Less than 100 mtrs to the rail line*
MAINRD	=	Set adjacent to a main road*
SEMPLOY	=	Size of the commercial complex by employment

Note: Dummy variables denoted by asterisk.

5.1.3 Rationale for choice of functional form

This research adopts a semi-logarithmic specification. The dependent variable is the natural log of adjusted property prices (ln*(ADJP)*). This variable has been transformed to reduce skewness and enable proportionate interpretation of the results. The continuous predictive variables listed above conform to a linear relationship with the dependent variable, with two exceptions. The first exception is distance to the CBD, which enters the estimation in log form (ln*(CBD)*). This is justified by the evidence of changing elasticity in its relationship with the dependent variable. On the other hand, building age observations are best squared (*BLDGAGE2*). The implication of the latter quadratic form is the existence of a minima or maxima turning point (see discussion in Section 3.2.5.1). While this may not occur within the given data set, the quadratic form in this case offers a useful transformation to improve overall model performance.

Some of the data are represented by dummy variables. These include building levels, distance to the station and distance to the motorway. The base cases for these are building level to the 3rd floor (*LV1*), 2,001 plus meters from the rail station (*ZONE5*) and 2,001 plus meters from the motorway (*MW4*), respectively. Other dummy variables included in *Equation 5.1* capture structural or locational characteristics. Details of these observations are provided in Chapter 3.

5.1.4 Expectation of model results

The data comprise structural, accessibility and neighbourhood variables relating to strata property transactions in metropolitan Sydney. Structure is a vector of physical attributes relating to a property; accessibility referring to desirable locational attributes and measured by ease of access; and neighbourhood refers to aspects of community. Expectations regarding the coefficients generated by these variables are considered in this section.

Structural features may increase or decrease property value depending on their perceived advantage as judged by prospective buyers. It is expected that homes with a larger number of bedrooms, bathrooms and car spaces will be worth more than those with less, ceteris paribus. Likewise, villas and townhouses, full floor units and luxury apartments are expected to have a positive effect on property values. Units positioned at higher levels in a building complex generally have superior views and are therefore likely to attract a price premium compared with residences at lower levels. Other factors such as building age and the number of units (lot count) in a building complex are expected to have a negative sign. Regarding the former, newer housing stock is generally worth more than older properties, especially in relation to unit complexes. In the case of lot count, an increase in the number of building lots may dilute the utility residents derive from strata amenities and therefore lead to a property discount, compared with smaller complexes.[14]

Accessibility variables account for the ease of access to public amenities. The focus of this study is the impact of distance to a rail station on property prices, which is estimated by zones and controls for other factors including the size of the local commercial precinct. Zones one to four are each likely to register a positive coefficient as they represent areas of high rail accessibility. However, the magnitude of impact is likely to diminish as one moves from inner to outer zones.

Additional rail related accessibility factors considered in the study are the availability of parking and the number of lines serviced by a rail station. Both factors contribute to the quality of service, but only the latter is likely to have a positive influence on house prices. Regarding *PARKING,* the expected sign of the coefficient is unclear. While considered an important amenity parking is potentially less valuable for owners located nearby rail stations than those farther away. Indeed, nearby residents may consider the presence of parking a nuisance, given the likely impact on local road congestion.

Other non-rail accessibility factors are similarly expected to show a decay in property prices with increased distance from the amenities. Properties located closer to the CBD mean less travel time and therefore likely to be worth more than those located farther away. As a continuous variable the coefficient for distance to the CBD is expected to have a negative sign. In addition, proximity to a motorway entrance/exit ramp may also reduce travel time to the CBD and other large service centres. It is therefore expected that properties located close to a motorway entrance/exit ramp will be valued more highly than those properties farther away.

Neighbourhood variables account for local externalities. The observations associated with these variables comprise both physical and socio-economic characteristics. Positive externalities are expected to flow from locations with appealing attributes, which enhance lifestyle, improve access

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[14] See discussion Section 3.2.5.1

to education and employment, and/or project an image of socio-economic advantage. Hence, properties situated adjacent to a recreational body of water, a park or within the catchment area of a suburb's best performing school are likely to attract price premiums. Locations with higher incomes and wealth are also expected to encounter higher property prices compared with other properties (Section 3.2.5.3).

The expected sign of the coefficient for the variable representing suburb employment (*SEMPLOY*) is unknown. On the one hand, residents nearby locations with a large commercial complex derive greater benefits such as access to employment opportunities, shopping, professional services and cultural facilities, compared with those living at smaller centres. On the other hand, larger centres can also generate negative externalities associated with the environmental impact of increased road congestion. The net effect of positive and negative externalities associated with this variable will determine the coefficient sign.

Other neighbourhood characteristics generate negative externalities. These include the prevalence of crime and locational features that lead to forms of environmental pollution. In this study, the level of assault is used as a proxy for crime. The *ASSAULT* variable is expected to produce a negative coefficient. Similarly, the dummy variables representing properties on a main road (*MAINRD*) and those within 100 meters of a rail line (*LESS100*) are expected to incur the negative effects of congestion and/or noise pollution and therefore produce negative coefficients.

Two types of analysis are used to test the behaviour of variables. These tests involve the HPM and GWR. The calibration of the global HPM produces parameter estimates that represent 'average' behaviour. This form of analysis is often considered conclusive in studies that deal with house price estimations. However, there is increasing awareness of the need to consider spatial changes in the data. Criticism often aimed at quantitative analysis is that it deals in broad generalizations and has little interest in local variation. To resolve this issue, the relatively new GWR tool is employed in the present study.

5.1.5 HPM estimation results

The results of the HPM are presented below:

Model summary

	Unstandardized Coefficients		Standardized Coefficients		
Variable	**β**	**Std. Error**	**Beta**	***t***	**Sig.**
(Constant)	15.111	0.045	-	333.648	.000
BED	0.180	0.003	0.295	54.745	.000
BATH	0.116	0.004	0.157	28.859	.000
CAR	0.029	0.003	0.036	8.175	.000
VILTH	0.057	0.006	0.053	10.221	.000
LUX	0.048	0.013	0.022	3.796	.000
FLFLOOR	0.807	0.065	0.050	12.496	.000
LV2	0.066	0.006	0.052	11.003	.000
LV3	0.136	0.011	0.064	12.279	.000
LV4	0.196	0.014	0.078	13.662	.000
LOT	0.000	0.000	-0.017	-2.676	.007
BLDGAGE2	-6.649E-5	0.000	-0.112	-22.113	.000
ZONE1	0.131	0.010	0.097	13.111	.000
ZONE2	0.171	0.007	0.191	24.000	.000
ZONE3	0.131	0.006	0.155	20.206	.000
ZONE4	0.055	0.006	0.057	8.895	.000
PARKING	0.016	0.004	0.020	3.605	.000
LINES	0.016	0.001	0.059	10.696	.000
ASSAULT	-8.047E-5	0.000	-0.121	-22.660	.000
MW1	0.073	0.016	0.019	4.552	.000
MW2	-0.017	0.009	-0.009	-1.981	.048
MW3	0.030	0.005	0.031	6.294	.000
ln*(CBD)*	-0.303	0.005	-0.452	-67.072	.000
WTRSIDE	0.221	0.011	0.096	20.432	.000
SCHZONE	0.030	0.004	0.037	7.789	.000
Pc2KPLUS	0.023	0.000	0.293	55.361	.000
ADJPARK	-0.107	0.042	-0.010	-2.530	.011
LESS100	-0.032	0.005	-0.034	-6.800	.000
MAINRD	-0.029	0.005	-0.023	-5.500	.000
SEMPLOY	1.396E-6	0.000	0.035	6.739	.000
R^2	0.810		Adjusted R^2	0.809	
$F(29, 11881)$	1743.87		P-value (F)	.000	

Table 5.1 HPM with ln*(ADJP)* as the dependent variable

Table 5.1 shows estimation results based on averages for 23 locations across the metropolitan region. In this analysis, the dependent variable *ADJPRICE* is presented in logarithmic form, which facilitates interpretation of coefficients. Variables entered as the natural log provide coefficients representing elasticities, while those without transformation provide coefficients indicating percentage changes. The estimation results show an adjusted R^2 of 0.809, which suggests that a linear regression model is a good fit of the data. The *F* statistic and *P* value results also supports the model. Finally, the random behaviour of residuals and lack of heteroscedasticity reduce the likelihood of misspecification through omitted variables.

The following three sections review the results of the estimation process. It should be noted that references made to meeting or not meeting expectations relate to global model outcomes. Further discussion in Section 5.2 considers the variability of estimations at the local level and may add a number of caveats to global model findings.

5.1.5.1 Structural characteristics

The global coefficients of *BED*, *BATH* and *CAR* shown in Table 5.1 are as expected. These indicate positive results and each highly significant. An additional bedroom adds 18.0% to the value of a property; an extra bathroom adds 11.6%; and car space 2.9%. Based on an average property value of $453,000 this will increase prices by $81,540, $52,548 and $13,137, respectively.

The behaviour of variables relating to housing type, quality and aspect are also as expected. For example, villas and townhouses (*VILTH*) are more highly valued than units, adding an average 5.7% to property prices. Luxury units (*LUX*) command a price premium of 4.8% and full floor units add 80.7%, a figure that appears large but unsurprising to real estate professionals. Higher floor levels improve the view and incur a price premium. The results show that levels 4-9 (*LV2*) are 6.6% more expensive than those on level 1-3 (*LV1*), Levels 10-19 (*LV3*) attract a price premium of 13.6% and floors 20 plus (*LV4*) gain 19.6%. Each of these coefficients are significant at the 0.01 level.

As expected, negative coefficients are found for units in larger and older building complexes. Controlling for other factors, units in large complexes (represented by variable *LOT*) are found to be cheaper than those in smaller complexes and statistically significant at an alpha level of 0.01. Similarly, older buildings (see *BLDGAGE2*) attract a price discount compared with newer buildings, but at a diminishing rate. This is also significant at the 0.01 level.

5.1.5.2 Accessibility factors

After controlling for the size of the local commercial precinct and other factors, areas of high rail accessibility, represented by variables *ZONE1, 2, 3* and *4*, each register positive coefficients when compared with control *ZONE5*. Specifically, the property price premiums registered at *ZONE1, 2, 3* and *4* are 13.1%, 17.1%, 13.1% and 5.5%, respectively. This shows the rail accessibility price premium is highest at *ZONE2* ($77,463) and this drops away in *ZONE3* ($59,343) and again in *ZONE4* ($24,915).[15] The fact that the price premium in *ZONE1* is less than in *ZONE2* is not unusual. Negative externalities, such as congestion nearby station entrances, can adversely affect property values relative to those properties farther away (Section 2.1.5.4). The coefficient of each accessible zone is significant at the 0.01 level. The consistency of these findings across the whole metropolitan area is further tested in Section 5.2.

Other rail accessibility estimations relate to the quality of service. The results show the provision of state transit parking (*PARKING*) at station locations results in higher property values compared with station locations without such parking. Also, houses at station locations that service a larger number of rail lines (*LINES*) attract higher property premiums than those that service less. In each case the sign of the coefficient is significant at the 0.01 level. The results confirm expectations in relation to the impact of rail lines and provides new evidence regarding the effect of commuter parking.

Non-rail related accessibility factors include proximities to motorways and the CBD. Motorway access leads to a price premium in two of three accessibility zones. However, a negative mid zone suggests the overall direction of the results is indeterminable. The best conclusion is that the effect of proximity to motorway access is greatest up to 500 metres (*MV1*) adding approximately $33,000 to property prices. However, beyond this the behaviour of the coefficients is less clear.

The coefficient for ln*(CBD)* produces a negative sign which confirms expectations at the global level. The results suggest that the elasticity of distance to the CBD is 30.3%. This means, if the distance between the CBD and a property increases from 10 to 20 kilometres then property values fall by 30.3%. The CBD result is significant at the 0.01 level and the standardized beta coefficient shows this variable has the greatest impact on the dependent variable, at least in relation to this model.

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[15] Dollar premiums based on zone mean values.

5.1.5.3 Neighbourhood characteristics

As expected, the estimations confirm that positive externalities flow from locations with appealing attributes. Table 5.1 shows properties nearby a recreational body of water (*WTRSIDE*) attract a significant price premium of 22.1% compared with other properties. Properties located within the catchment area of the district's best performing school (*SCHZONE)* attract price premiums of 3.0% on average, significant at the 0.01 level. Also, locations with higher levels of income (*Pc2KPLUS*) lead to higher property prices, as expected. However, the sign of the coefficient for properties adjacent to a park (*ADJPARK*) is counter to expectations and is significant at the 0.05 level. This suggests that the benefits of living nearby a recreational park may be offset by the congestion and perhaps anti-social activities associated with these areas at different times of day or night.

Other residential properties that incur negative externalities include those situated on a main road (*MAINRD*) or within 100 meters (*LESS100*) of a rail line. The results of dummy variable estimations indicate these properties attract a 1.3% and 1.4% discount, respectively (significant at the 0.01 level). Also, the continuous variable representing the incidence of assault (*ASSAULT*) behaves as expected. In this case, higher rates lead to a reduction of property prices. The effect is highly significant, and the standardized beta coefficient indicates this variable has a relatively large influence on the prices, given a change in its standard deviation.

Prior to estimation of *Equation 5.1* the expectation regarding the effect of local commercial district size (*SEMPLOY*) on property prices was unknown (Section 3.2.5.3). As discussed, larger locations offer greater benefits including access to jobs, shopping, services and cultural facilities, although they are likely to encounter more road congestion than smaller centres. Table 5.1 shows that the net result of the positive and negative externalities associated with location size produces a positive coefficient, significant at the 0.01 level. This means residents at locations with a larger surrounding commercial complex pay a price premium compared with those at smaller centres.

5.2 GWR4 analysis

As previously discussed, the GWR modelling technique reveals the impact of rail stations over space. GWR examines local processes that give rise to spatial autocorrelation and spatial heterogeneity. While the global HPM used in Section 5.1 provides an important indication of the average effect of rail accessibility across the focus region, the GWR local model highlights evidence of non-conformity at the sub-region level.

As discussed in Chapter 3, GWR is an extension of the global regression model, which means that similar techniques are used to establish the best equation for modelling purposes. However, as Du and Mulley (2007) point out the best global model does not necessarily lead to the best GWR model. In this study, dummy variables that may give rise to multicollinearity are excluded from the model unless they convert to continuous variables. A stepwise approach is then employed to select the appropriate variables from the remaining candidates shown in Section 5.1.2. For the purpose of this study, the best equation is specified with the variables set out in the table below.

Vector	Variable	Description
Dwelling Prices	$\ln(ADJP)$	Log of the adjusted transaction price
Structural	BED	Number of bedrooms
	$BATH$	Number of bathrooms
	CAR	Number of car spaces
	$BLDGAGE2$	Building age squared
	LOT	Total lot size of strata plan
	$AVLVL$	Average building floor Lvl
Accessibility	$\ln(STN)$	Log of distance to the rail station
	$LINES$	Number of rail lines serviced
	$\ln(MW)$	Log of distance to the motorway entrance
	$\ln(CBD)$	Log of distance to CBD
Environmental	$Pc2KPLUS$	Percentage of SA1 residents who earn $2000 or more
	$ASSAULT$	Rate of assault at the location
	$SEMPLOY$	Size of the commercial complex by employment at the location

Table 5.2 GWR model variables

This study employs a semiparametric Gaussian GWR model described as:

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i) x_{ik} + e_i \tag{5.2}$$

where:

(u_i, v_i) are coordinates of the *ith* point in space.

$\beta_k(u_i, v_i)$ is the realisation of the continuous function $\beta_k(u_i, v_i)$ at point i.

GWR is highly demanding of processing time. To facilitate the application of GWR we reduce the data set by collapsing the original 11,912 observations into a file of 857 SA1 districts. Apart from assisting with GWR processing, this has additional advantages in that it utilizes the full data set and enables visual analysis through mapping at the SA1 level. However, a concern with this approach is whether the observations sufficiently represent the SA1 districts. For this reason, random samples up to 1,500 observations are taken from the original data set to compare model performance and the behaviour of variables. The similarity of model performance and variable behaviour in these tests confirm the SA1 level aggregation is an adequate representation of the data and that there can be confidence in the findings.

A tabular data set has been constructed for GWR version 4 application. This contains fields of dependent and independent variables together with latitude and longitude coordinates. Files used in GWR4 are text format and comma delimited (CSV). As alluded to earlier, GWR4 has the facility to read dbase files and interfaces with ESRI databases containing geographic objects, including ABS census districts. Following an outline of the GWR4 processes and results (Sections 5.2.1 and 5.2.3), the mapping facility will be employed to further enhance our understanding of spatial variability in regard to rail induced property value uplift.

5.2.1 GWR global regression result

In the first instance, the GWR model estimates coefficients using global regression. The analysis delivers the following results:

Residual sum of squares	17.69832
Number of parameters	14
ML based global sigma estimate	0.14379
Unbiased global sigma estimate	0.14498
-2 log-likelihood	-891.03043
Classic AIC	-861.03043
AICc	-860.45900
BIC/MDL	-789.74638
CV	0.02145
R^2	0.79660
Adjusted R^2	0.79321

Table 5.3 GWR global model diagnostics

Variable	Estimate	Standard Error	t(Est/SE)
Intercept	15.04435	0.12687	118.57790
ln*(STN)*	-0.06190	0.00797	-7.77123
ln*(MW)*	0.02820	0.00868	3.24811
ln*(CBD)*	-0.27056	0.01353	-19.99650
BED	0.18466	0.01359	13.58690
BATH	0.13180	0.01685	7.82119
CAR	0.04566	0.01441	3.16949
AVLVL	0.01354	0.00489	2.76812
SEMPLOY	0.00000	0.00000	3.84788
BLDGAGE2	-2.8E-05	0.00001	-2.23256
LOT	-0.00036	0.00022	-1.63547
ASSAULT	-9.8E-05	0.00001	-8.74119
LINES	0.00677	0.00418	1.62062
Pc2KPLUS	0.02291	0.00125	18.30634

Table 5.4 GWR global results

GWR automatically generates fixed global coefficients to assess the magnitude and significance of all variables included in the data set. Inevitably, some coefficient results differ from equivalent outcomes posted in Table 5.1. This is due to the fact the GWR model has less variables than the original HPM and some transformation has taken place. However, a comparison of Table 5.1 and Table 5.4 shows that GWR global Adjusted R^2 result (0.793) is only slightly less than that of the original HPM (0.809).

Our primary interest in Table 5.4 is the coefficient for station proximity. In this model, the log of distance to the station (ln*(STN)*) substitutes for the zone dummy variables used in Section 5.1.[16] The log distance shows that the elasticity of distance to the station is -0.062 and significant at the 0.01 level. Therefore, ceteris paribus, if the distance between a property and rail station doubles, the price of the property falls by 6.2%. This confirms the strong relationship between property value and rail accessibility when a continuous data set is used. However, it does not reveal if there is variability in the coefficient across Sydney metropolitan area.

[16] ln*(STN)* estimation is based on the same network distance observations used for the zone variables in Section 5.1.

5.2.2 Determining spatial variability

The next step is to test whether distance to the station and other variable coefficients are subject to spatial variation. The 'Difference of Criterion' is used to determine if there are 'fixed' or 'local' variable candidates for model specification. Each variable is initially assigned according to best assessment. The resulting 'Difference of Criterion' generated by the model indicates the spatial variability of each coefficient. If the 'Difference of Criterion' is positive this suggests there is no spatial variability in the local term. The GWR facility GtoL (Global to Local) and the reverse LtoG (Local to Global) are used to allocate each variable according to best fit. Therefore, each global term is a candidate for switching to a varying term and vice versa. If variables remain constant over space, they are allocated to the 'fixed' component of the model and if they are variable over space they are allocated to the 'local' component. The results of this process are shown in the following section.

5.2.3 GWR model with fixed and local components

The 'Difference of Criterion' generates a positive term for variables *BATH*, *AVLVL*, *LINES* and *Pc2KPLUS*. The coefficients of these variables are found to have no spatial variability locally and are therefore assigned as 'fixed' elements in the model. The coefficients of the remaining variables, including ln*(STN)*, exhibit some spatial variability and are consequently assigned to the 'local' component of the model. The model is then rerun with the following results:

Residual sum of squares:	7.95623
Effective number of parameters (model: trace(S)):	116.25688
Effective number of parameters (variance: trace(S'S))	92.56568
Degree of freedom (model: n - trace(S)):	739.74312
Degree of freedom (residual: n - 2trace(S) + trace(S'S)):	716.05192
ML based sigma estimate:	0.09641
Unbiased sigma estimate:	0.10541
-2 log-likelihood:	-1,575.41460
Classic AIC:	-1,340.90086
AICc	-1,303.30937
BIC/MDL:	-783.66446
CV:	0.01346
R^2	0.90856
Adjusted R^2	0.89067

Table 5.5 GWR local and fixed model diagnostic information

Variable	Estimate	Standard Error	*t (*estimate/SE)
BATH	0.11728	0.01450	8.08993
AVLVL	0.01448	0.00559	2.59206
LINES	0.04108	0.00746	5.50750
Pc2KPLUS	0.01025	0.00139	7.38290

Table 5.6 GWR fixed (global) coefficients

Variable	Min	Max	Range
Intercept	6.38476	20.67530	14.29053
ln*(STN)*	-0.10428	0.06714	0.17142
ln*(MW)*	-0.12221	0.11526	0.23747
ln*(CBD)*	-0.94675	0.69572	1.64247
BED	0.06992	0.42569	0.35577
CAR	-0.09262	0.32797	0.42060
SEMPLOY	-0.00006	0.00016	0.00022
BLDGAGE2	-0.00025	-0.00003	0.00027
LOT	-0.00232	0.00143	0.00375
ASSAULT	-0.00080	0.00098	0.00177

Table 5.7 GWR varying (local) coefficients

Source	SS	DF	MS	F
Global Residuals	17.698	842.000		
GWR Improvement	9.742	125.948	0.077	
GWR Residuals	7.956	716.052	0.011	6.96142

Table 5.8 GWR ANOVA

SS = sum of squares, DF = degrees of freedom, MS = mean squares, F = F value

For the purpose of this study, the GWR model diagnostics offers three principle measures to explain GWR local model performance compared with a global model approach. First, they indicate an increase in the adjusted R^2 from 0.79 to 0.89 implying that GWR provides a better explanation in terms of how well the model explains housing prices, after taking into account the degrees of freedom. Second, the summary statistics show changes to the AIC from -860.45900 to -1,303.3094. A lower AIC suggests a better fit and the models are considered statistically significantly different if these values differ by more than three points. Finally, an ANOVA table

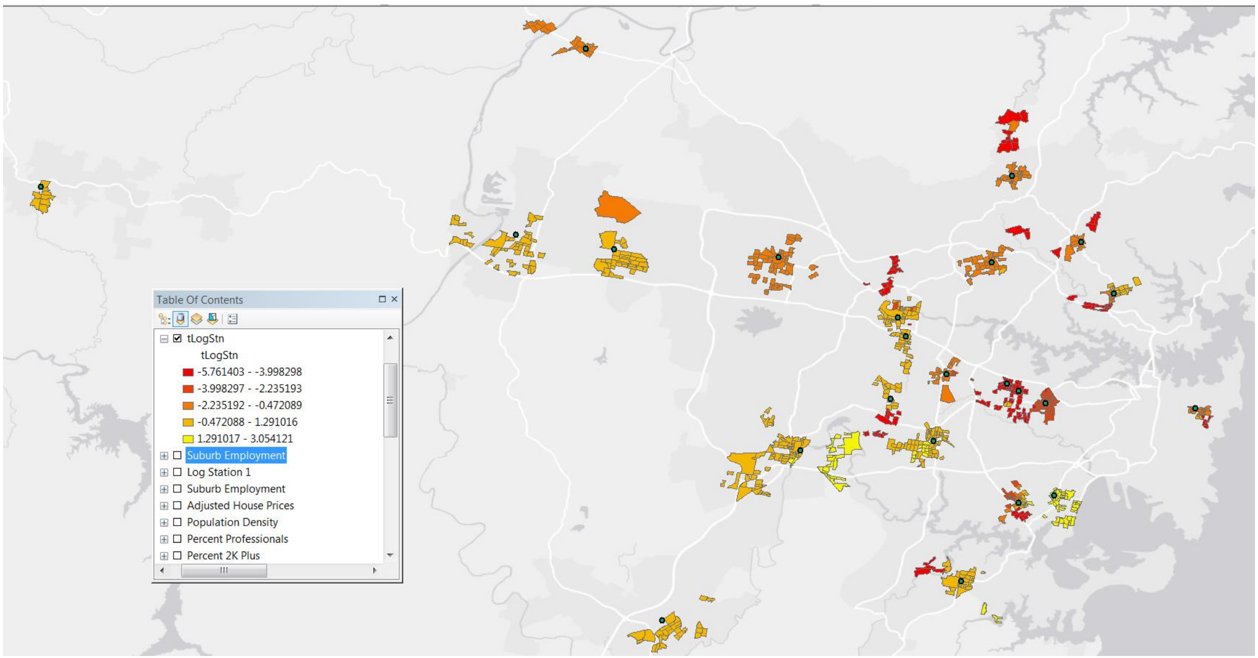
(Table 5.8) tests the hypothesis that the GRW model used in this study offers no improvement over the global model. In this case, the *F test* result suggests there is significant improvement and the hypothesis is rejected.

The sign and significance of the fixed coefficients produced by GWR (Table 5.6) confirm results generated by the HPM (Section 5.1.5). However, local components of the GWR model identify variances in a number of estimations, including ln*(STN)* (Table 5.7). This suggests the global estimation does not satisfactorily explain the relationship between these variables and house prices across the Sydney metropolitan area. Regarding ln*(STN)*, the maximum (and upper quartile) values shown in Table 5.7 indicate the existence of positive coefficients at the local level. This suggests our expectation that the variable is always negatively correlated with house prices is uncorroborated. Further investigation of this phenomenon is undertaken in the following section.

5.3 Mapping ln*(STN)* *t*-values

GWR reveals that ln*(STN)* has a varying local coefficient. ArcGIS mapping can be used to identify how ln*(STN)* varies over space. The map below indicates *t*-values associated with this variable, at each SA1. A cursory glance at the map shows considerable variation in *t*-values. However, after accounting for factors that may give rise to anomalous readings, it appears that distinguishable patterns emerge. For example, examining the map from left to right shows that highly significant, negative *t*-values begin to appear in the *WEST CENTRAL* district and are generally more highly concentrated in the *CENTRAL*, *SOUTH*, *WEST CENTRAL* and *NORTH* districts.

The map also highlights two regions of positive *t*-values (yellow clusters) found at the South East, Kogarah bayside suburb and the South West, Chipping Norton Lakes area. In both areas, the primary attraction is the waterside aspect, which counters and dominates the effect of rail accessibility. The effect of such competing local geographical attractions is clearly identified in the map below.



Map 5.1 *t*-values representing the impact of rail access

Setting aside, for a moment, the anomalous clusters (see further discussion in Section 5.4.2) the map suggests the need for investigation of the differences in the effect of rail access between the South West and West districts, on the one hand, and the eastern sector districts on the other. Section 5.4 reverts to hedonic price modelling to explain how the impact of rail access differs in these sectors. In this exercise, dummy variables represent metropolitan districts shown in Map 5.1, Section 3.2.5.3.

5.4 HPM analysis with district variables

District variables are introduced to the HPM in order to investigate the findings of spatial variability revealed in GWR modelling. The original HMP model (Section 5.1) is respecified to accommodate these variables. To minimize multicollinearity some variables have been eliminated from the original model specification. The natural log distance to the station, used in the GWR model, again substitutes for *ZONES1234* to facilitate comparisons of the overall effect of rail access on property value uplift. The resultant estimated district coefficients are shown in the table below.[17]

[17] It is not necessary to confuse matters by reporting a second set of estimates using hedonic variables similar to those in Section 5.1.5

Districts	β	*t*
SOUTH	-.082	-13.528
WESTCEN	-.353	-56.711
WEST	-.584	-74.561
SOUWEST	-.544	-69.236
NORTH	-.106	-18.661
ln*(STN)*	-.063	-22.684

Table 5.9 District coefficients
Dependent Variable: ln*(ADJP)*

The most pertinent information to emerge from the estimations is shown in Table 5.9. This indicates the variation in the impact of metropolitan districts on residential property prices. Relative to the central district, the results show that more remote western districts are likely to exhibit lower house prices than other districts. The estimations also show the differences at the regional level are greatest in the West/South West (WSW). These districts correspond to those that have relatively low significance in regard to the coefficient for ln*(STN)*. Given that our research purpose is to understand the impact of rail access, it is therefore important to test whether rail access has a similar impact on property prices across the metropolitan area. In particular, our test should compare WSW districts with Central, North, Central West and South (CNCWS) districts. The results of this exercise are shown in Table 5.10.[18]

Variable	West and South West districts (WSW)		Central, North, Central West and South districts (CSCWS)	
	β	*t*	β	*t*
ln*(STN)*	-0.033	- 5.063	-0.105	-30.446
R^2	0.671		0.691	
Adjusted R^2	0.668		0.690	
F	252.772		937.724	
P-Value (*F*)	.000		.000	

Table 5.10 WSW and CNCWS district coefficients
Dependent Variable: ln*(ADJP)*

[18] Full results are provided in Appendix B, Table B.1

Table 5.10 examines the coefficient for the variable ln*(STN)*, which is the continuous equivalent of the discrete zone coefficients used in Table 5.1. ln*(STN)* estimate of -0.63 is consistent with the results provided by the GWR fixed model (Table 5.4). However, the table above shows the coefficient for ln*(STN)* varies when just two metropolitan regions are considered. This suggests that the more remote western districts (WSW) produce a lower coefficient than those in the remaining districts (CNCWS). This implies that rail accessibility generates different proximity premiums depending on geographical location. In particular, residents in areas less densely occupied by employment centres and with greater commuter distances appear to value rail access less than other areas. It suggests that the global model spatial averages tend to underestimate the price effect of accessibility in the CNCWS districts and overestimate its effect in the WSW districts.

5.4.1 Matching expectations

The preceding analysis demonstrates the underlying variability in the behaviour of variables that influence residential property prices. For example, Table 5.7 shows that coefficients for ln*(STN)*, ln*(MW)*, ln*(CBD)*, *CAR*, *SEMPLOY*, *LOT* and *ASSAULT* change signs over the range of observations, which is hidden using the conventional HPM alone. Following a comprehensive investigation of local variable behaviour, using both HPM and GWR, it is now possible to compare outcomes and expectations based on an improved understanding of spatial heterogeneity. This assessment is summarized in Table 5.11.

Variables	Expected Sign	HPM Estimated Parameter	Sig. at 0.05	Matches Expectations (✓agree, *x* disagree)	GWR Local Variability (✓ variable, *f* fixed)
BED	+	+	✓	✓	✓
BATH	+	+	✓	✓	***f***
CAR	+	+	✓	✓	✓
VILTH	+	+	✓	✓	n/a
FLFLOOR	+	+	✓	✓	n/a
LUX	+	+	✓	✓	n/a
AVLVL	+	+	✓	✓	***f***
BLDGAGE2	-	-	✓	✓	✓
LOT	-	-	✓	✓	✓
ln*(STN)*	-	-	✓	✓	✓
PARKING	unk	+	✓	n/a	n/a
LINES	+	+	✓	✓	***f***
ln*(CBD)*	-	-	✓	✓	✓
ln*(MW)*	-	+	✓	***x***	✓
WTRSIDE	+	+	✓	✓	n/a
ADJPARK	+	-	✓	***x***	n/a
SCHZONE	+	+	✓	✓	n/a
Pc2KPLUS	+	+	✓	✓	***f***
SEMPLOY	unk	+	✓	n/a	✓
ASSAULT	-	-	✓	✓	✓
MAINRD	-	-	✓	✓	n/a
LESS100	-	-	✓	✓	n/a

Table 5.11 Expectations and outcomes
unk = unknown, n/a = not applicable

The last column of Table 5.11 indicates that global assessments are subject to caveats. In each of these cases GWR has identified abnormal variable behaviour, at least in some localities. GWR operates on the assumption that if parameters exhibit some degree of spatial consistency, then values nearby those being estimated should have relatively similar magnitudes and signs (Fotheringham, Brunsdon & Charlton 2002, p. 52). In the cases identified above there are clusters, which do not conform to this assumption.

The nine irregularities identified in Table 5.11 fall into one of two categories. The first category includes variables where the sign of the coefficient remains constant over a large range of observations. Estimations of *BED* and *BLDGAGE2* are examples of this category. Here, a consistent sign confirms our expectations of the variables' behaviour. In the remaining cases, the magnitude of the estimate is subject to both considerable variation and a change in sign. The latter category includes ln*(STN)* and *SEMPLOY*, which has implications for assessment of the hypotheses and also strategic planning for Stage 2 research (see Chapter 7).

5.4.2 Implications of spatial variability

Particularly relevant to this study is the behaviour of variable ln*(STN)*, which substitutes for the discrete zone variables referred to earlier. The fact that the estimate for ln*(STN)* changes in magnitude and sign over space means that the concept of residential price decay and station distance does not uniformly apply across the Sydney metropolitan area. This means the concentric circles around the station do not always display a positive coefficient. Indeed, in some cases property values may rise with greater distance to the station. This phenomenon also applies to the *SEMPLOY* variable.

In summary, Stage 1 analysis reveals considerable spatial variation of residential property prices across metropolitan districts, and also minority circumstances where the dominance of rail access, as an attractor, is challenged by proximity to the waters' edge. These conditions may, or may not, lead to distortions in the analytical processes of Stage 2, the next research phase. Stage 2 deals with the impact of rail access on local demographic characteristics. To the extent that property prices influence demographic patterns means that proximity to any waterside location may be of consequence when seeking to isolate the effect of rail. This suggests the need for a continuous control variable to adequately control for waterside influence when considering the geographical factors that lead to demographic sorting.[19]

[19] Rather than a dummy variable representing waterside residences, Stage 2 research uses a new continuous variable defined as proximity to a recreational body of water (ln*(RBW)*). An analysis of Map 5.1 suggests this may improve estimation of the waterside effect. Subsequently, the estimates prepared in Section 5.2.3 have been reassessed using the new variable with no significant change to the section's findings.

6 Stage 2 Results: Residential Sorting and Proximity to Rail Access

For many home-seekers rail stations enhance the attraction of nearby neighbourhoods. Stage 2 research examines how this might manifest itself into differences in the demographic profile of residents located in neighbourhoods with high rail access compared to locations with low access. The results of this study are presented as distributions of residents according to various socio-economic characteristics. A complete list of demographic variables and neighbourhood variables pertinent to this study are provided in Table 6.1.

Similar to Stage 1 analysis, this aspect of the study considers rail access primarily as a matter of geographic proximity. Concentric rings surrounding a rail station define four zones with different degrees of accessibility. The fifth zone, beyond 2,000 meters from the rail station, is essentially considered a similar locality but with low rail access. This zone acts as a control location in the analytical process.[20] Two supplementary factors relating to rail accessibility (*PARKING* and *LINES*) are also included in this study along with various geographical predictors that complete the spatial analysis.

The data are aggregated at the SA1 neighbourhood level, which is the smallest unit for release of ABS census data. Of these geographical units, only those with observations in Stage 1 analysis are included in this study. As in the previous chapter, the appropriate SA1 neighbourhood data are assigned to each house transaction observation, with the latter representing a point of distance to the nearest rail station.

Another matter related to the structure of the data set concerns the delineation of SA1 boundaries. In some cases, the statistical areas cross the boundaries of the rail-accessible zones, particularly in locations where population densities are low. To address this issue, the 11,912 observation points used in Stage 1 research are each allocated to their appropriate zone and the SA1 is split according to the demographic area that encompasses these observations. Splitting neighbourhoods by zones effectively increases the number of SA1s observations from 857 to 1,107[21]. This process has the advantage that it enables zone-wise analysis of SA1 data. It also aligns perfectly with Stage 1 observations, which means it delivers accurate and consistent estimates of all proximity variables used in Stage 2 analysis.

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[20] See discussion in Chapter 3 relating to accessibility zones.

[21] 857 observations were used in Stage 1 research, see Section 5.2.

Variable	Description	Source
Pc2KPLUS	Percentage of the population earning more than two thousand dollars per week	ASB (SA1 level)
PcPROF	Percentage of professionals in the community	ABS (SA1 level)
PcUNIQL	Percentage of University-qualified	ABS (SA1 level)
PcUEMP	Percentage unemployed	ABS (SA1 level)
AVAGE	Average resident age	ABS (SA1 level)
PcAUSB	Percentage of Australian born	ABS (SA1 level)
PcFAMDEP	Percentage of households with dependent children	ABS (SA1 level)
PcRENTER	The percentage of residents who rent	ABS (SA1 level)
AVMVOWN	The average number of motor vehicles per household	ABS (SA1 level)
PcARP	The percentage of attached residential properties	ABS (SA1 level)
PcTRAVT	The percentage of residents who use rail travel as the first or only means of transport for work commute	ABS (SA1 level)
SA1POPDN	SA1 population density	ABS (SA1 level)
ln*(RBW)*	Log distance to the nearest recreational body of water	GPS
GZ1234	Grouped or combined estimate for high rail access zones	Calculated from database

Table 6.1 Stage 2 variables relating to demographic profile

6.1 The analytical process

The purpose of this study is to assess whether access to rail transit is associated with neighbourhood demographic characteristics. Before this relationship is examined, it is appropriate to consider a number of preliminary matters, which may have a bearing on these findings. First, Section 6.2 tests the validity of the presumption that neighbourhood property premiums associated with rail access (identified in Stage 1 results) correspond with significant uptake of rail transit services at the research locations. Second, Section 6.3 examines the correlation between the prevalence of population characteristics and train usage to determine if there is evidence of rail travel preference amongst various demographic groups. Third, Section 6.4 explores the relationship between population density and residential building types and explains how this may influence residential sorting at neighbourhoods with high rail accessibility. Finally, Section 6.5 addresses the primary focus of the chapter. In particular, this section estimates the degree to which the concentration of demographic characteristics corresponds with proximity to rail transit. The results of these estimations are assessed in light of findings from earlier sections in this chapter.

The four-part analytical approach described above involves a variety of statistical tests and visual representations to convey pertinent information regarding the process of residential sorting. The results of these investigations, also contained in these sections, are primarily intended to explain the spatial dependency of demographic characteristics and how they relate to rail access proximity. In addition, a contextual aspect of this research is designed to provide insights into the relative importance of various other factors that affect residential sorting. The specific objectives of each test and the analytical processes employed are further elucidated in the following sections.

6.2 The relationship between zone price premiums and rail patronage

Prior to an investigation of the relationship between socio-economic variables and access to rail transit it is important to establish if the latter, represented as a geographical proxy, manifests itself in terms of tangible benefits for residents. Therefore, the analysis in this section tests the legitimacy of the presumption that rail induced property price premiums found in Stage 1 results correspond to significant rail transit consumption. If this is true, then residents in zones with high rail accessibility account for the property price premiums associated with nearby rail transit services. If this is not the case, then price premiums in the accessibility zones are more than likely a result of other factors.

Test and results

An OLS regression model is constructed to investigate the extent of demand for rail services and demonstrate how this is influenced by proximity to rail stations, along with other accessibility features and geographical factors (*Equation 6.1*). In this model, explanatory variables comprise distance intervals from each station represented by accessibility *ZONE1*, *2*, *3* and *4*. Other rail accessibility factors are the number of rail lines serviced by each station (*LINES)* and the availability of station car parking (*PARKING)*. In addition, the size of the commercial complex at each location (*SEMPLOY*) and the metropolitan districts (*SOUTH, WESTCEN, WEST, SOUWEST*, *NORTH*) are included in the model. Data are obtained from a repository of ABS Census findings at SA1 level (see Section 3.3.5). The equation is presented as follows:

$$PcTravT = f(ZONE1234, LINES, PARKING, SEMPLOY, SOUTH, WESTCEN, WEST, SOUWEST, NORTH) \qquad (6.1)$$

where:

$Zone5$ and $Central$ are the base case variables for zones and metropolitan districts, respectively.

	Coefficient	Std. error	*t*-ratio	Sig
Constant	17.710	0.910	19.46	.000
ZONE1	22.789	1.540	14.80	.000
ZONE2	21.008	.832	25.24	.000
ZONE3	15.861	.684	23.20	.000
ZONE4	6.454	.576	11.20	.000
LINES	2.410	.219	11.02	.000
PARKING	0.258	.598	0.431	.667
SEMPLOY	0.000	3.30E-05	0.540	.589
SOUTH	-3.328	1.006	-3.310	.001
WESTCEN	-11.294	.937	-12.05	.000
WEST	-15.452	1.162	-13.30	.000
SOUWEST	-16.638	.970	-17.14	.000
NORTH	-7.502	1.035	-7.250	.000
R^2	0.700	Adjusted R^2		0.696
$F(12, 1093)$	255.21	P-value (F)		9.70E-307

Table 6.2 Coefficients with *PcTRAVT* as the dependent variable

The model is estimated using robust standard errors[22] and the results are shown in Table 6.2. In this model, the adjusted R^2 indicates that the predictor variables account for 69.6% of the variation in the dependent variable. Each independent variable registers a variance inflation factor (VIF) below 3, which suggests the probability of multicollinearity is low.

The zone coefficients show that residents closer to a station are more likely to use train travel, as their first or only mode of transport for commute to work, than those located farther away. Also, district coefficients reveal that *CENTRAL* has the highest proportion of rail users in all zones, while rail usage is lowest in *WEST* and *SOUWEST*. This aligns with results in Section 5.4, which shows that access to rail in the latter districts have less impact on property prices compared to other metropolitan districts. Across the metropolitan area, rail usage is higher in the eastern districts where employment centres are more common and average commuter distances are smaller. Overall, these attributes mean superior connectivity provided by rail services in the eastern districts.

[22] Reported results do not change quantifiably when Robust Standard Errors are applied.

Other accessibility factors and the variable representing size of the local commercial complex deliver positive coefficients. Table 6.2 shows each additional line serviced by a rail station ($LINES$) increases the proportion of the local community that use rail transport by 2.41 percentage points. While the variable for the provision of parking at rail locations ($PARKING$) and the proxy for commercial complex ($SEMPLOY$) both have positive coefficients, neither are significant at any level.

The results of this analysis clearly demonstrate the spatial dependency of rail transit uptake. Importantly, the analysis reveals relatively stronger demand for rail services in areas closest to the station and less frequent usage with greater distance from the point of rail access. This suggests that the proximity premiums found in Stage 1 results are likely related to the rail station and not simply due to other local amenities. Hence, households located in rail accessibility zones incur the costs of premiums associated with the benefits of rail transit, which are capitalized into property values. This leads to the conclusion that demographic groups, predominantly concentrated in accessibility zones, incur a larger proportion of rail induced property price premiums than other groups.

6.3 Correlation between train travel and demographic variables

The purpose of this analytical exercise is to understand the relationship between the proportion of train users and the prevalence of various demographic groups in the study area. This test involves bivariate correlation analysis designed to produce correlation estimates (Table 6.3). These estimations should not imply a causal relationship between the variables, as there may be a number of other factors that influence demographic patterns. Nevertheless, it is important to understand the sign of the relationships and where they are strongest and least strong.

Variable Correlation	Coefficient	
PcTRAVT/Pc2KPLUS	0.066	**
PcTRAVT/PcUNIQL	0.692	***
PcTRAVT/PcPROF	0.434	***
PcTRAVT/PcUEMP	0.236	***
PcTRAVT/AVAGE	-0.197	***
PcTRAVT/PcAUSB	-0.715	***
PcTRAVT/PcFAMDEP	-0.347	***
PcTRAVT/PcRENTER	0.489	***
PcTRAVT/AVMVOWN	-0.674	***

Table 6.3 Coefficients for train travel and demographic variables
** Significant at the 0.05 level. *** Significant at the 0.01 level.

The first four variables relate to income, educational attainment and employment. Regarding *Pc2KPLUS*, Table 6.3 indicates a positive coefficient, which means greater concentration of high-income residents is associated with higher train usage. The analysis also reveals a relatively low correlation coefficient and one that is the least significant of all coefficients in the table. This is not unexpected as Stage 1 HPM analysis includes both *ZONES* and *Pc2KPLUS* as independent variables without evidence of pronounced collinearity. Therefore, Stage 1 predictive variable diagnostic results anticipate the outcome in Table 6.3.

In Stage 1 analysis, when considering the relationship of predictive variables with property prices, *Pc2KPLUS* acted as a proxy for *PcUNIQL* and *PcPROF*. However, it is interesting to note that the behaviour of these variables is more definitive in its response to rail access. Both *PcUNIQL* and *PcPROF* have a relatively strong positive relationship with *PcTRAVT*, which implies that residents with higher educational attainment and professionals are potentially more likely found in areas with higher rather than lower train usage. Similarly, *PcUEMP* has a highly significant positive sign, which suggests that higher levels of rail patronage correspond with higher concentrations of unemployed.

The remaining five demographic variables relate to age, Australian born and various life cycle and life-style statistics. The results suggest that areas with a larger proportion of train users correspond with a slightly higher concentration of younger residents *(AVAGE)*. Perhaps more apparent are the higher levels of train usage associated with larger numbers of immigrants *(PcAUSB)*, renters

(PcRENTER) and families without dependants *(PcFAMDEP)*. The final demographic variable concerns motor vehicle ownership (*AVMVOWN*). This returns a negative, significant correlation coefficient, which suggests less vehicle ownership in areas where train usage is higher.

Overall, the analysis shows that areas with higher train usage correspond with different concentrations of demographic groups. The sorting of residents is the manifestation of household location decisions, which are influenced by several factors. For example, home-seekers who derive utility from rail transit must consider the costs associated with access, which considers the property price premiums nearby rail stations and the opportunity cost of alternative transportation modes. Apart from cost/benefit matters, home-seekers must also consider the suitability of the housing types in neighbourhoods nearby rail stations. Section 2.2.2.3 shows rail stations bring a high level of foot traffic, which stimulates retail services and employment opportunities. Higher levels of commercial activity encourage in-movers who seek these amenities and this, in turn, potentially leads to greater population density and the emergence of particular housing types. Higher density and the types of housing nearby rail stations may satisfy some, but not all, demographic groups. The following section examines the pattern of population density and housing types within the study area and the implications this has for the sorting of residents.

6.4 The effects of population density and housing types on residential sorting

This section investigates patterns of population density and housing types and how this may influence residential sorting nearby rail stations. Only those neighbourhoods that encompass observations used in Stage 1 analysis are included in the estimation process. This approach retains the integrity of the data set which seeks to capture observations aligned with the rail stations targeted for study. Demonstrating how local characteristics vary over space will help to explain the emergence of demographic patterns discussed later in the chapter.

6.4.1 Population density

Before examining specific SA1 level results it is helpful to briefly consider the developing patterns of population density across the Sydney metropolitan area. An important part of this process has been the response, in recent decades, to policies that promote metropolitan population ‘infill’ and less on ‘greenfield’ development (see Section 4.1). During that time, there has also been greater emphasis on more intensive use of existing public infrastructure. This has dramatically altered the pattern of Sydney metropolitan population density. The NSW Department of Planning has examined these changes and produced a concentric density profile based on the CBD. Department research reveals a swift transition towards the end of the last century, with population movements shifting in favour of the inner and middle ring suburbs (Figure 6.1). This has clear implications for the density of dwellings and changing demographic profile in these areas.

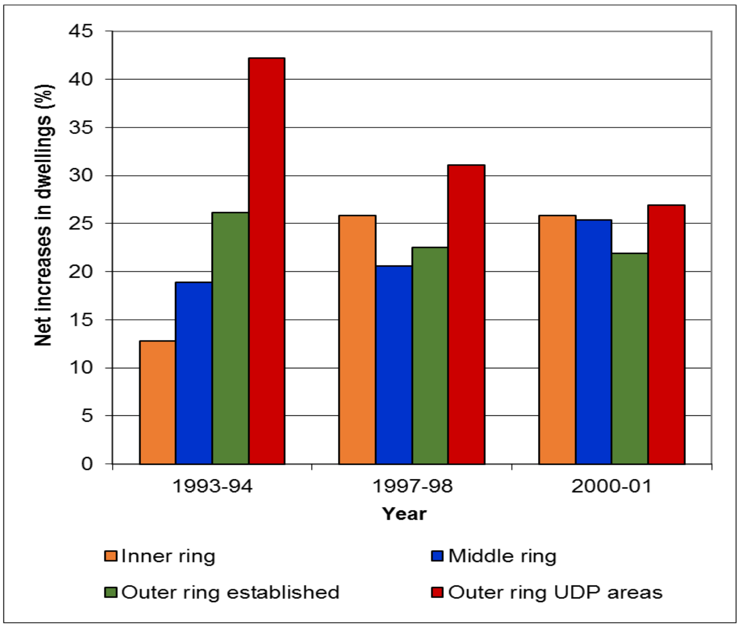
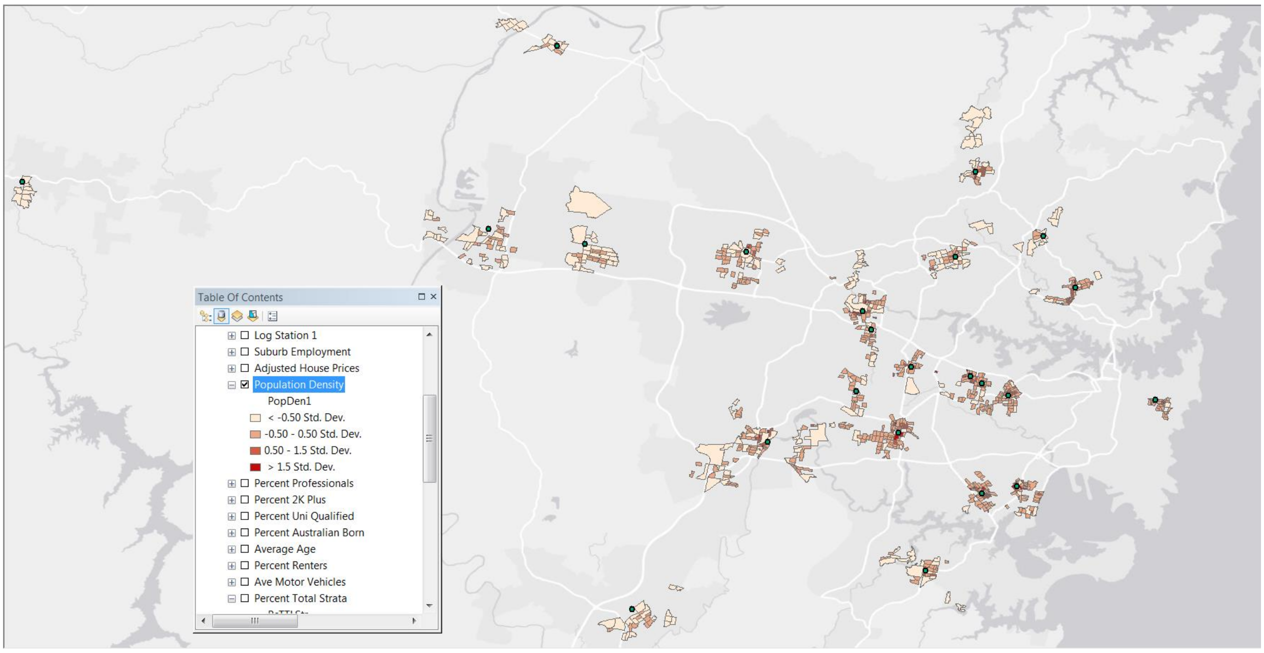


Figure 6.1 Regional proportions of net increases in dwellings, Sydney 1993–2001
(Department of Environment and Planning 2003)

The pattern of settlement population density that emerges in 2011 is revealed in Map 6.1 presented below. This map indicates locational differences of population density using the standard deviations of *SA1POPDN* for areas included in the study. In this map, colour references signify the range of standard deviations, plus or minus from the mean.



Map 6.1 Standard deviation of population density by SA1

The map confirms that inner suburbs are more densely populated than those on the fringe of the metropolitan area. There is also some evidence that suggests, at least in inner suburbs, of a tendency for greater density nearby rail stations. This increased density reflects the strong demand for land in these areas and is consistent with estimates of proximity premiums found in Stage 1 results. Population density also has implications for residential sorting and ultimately the demographic profile nearby rail hubs.

Dwelling types at high-density rail-serviced locations are essentially demand driven and generally satisfy the needs of in-movers. However, pre-existing conditions of density and price constraints conflate to produce limited dwelling configurations and tenure types that may not be suited to all demographic groups. This reinforces the notion of selective tenancy at rail locations based on prospective residents' perceptions of the economic utility provided by rail transit, moderated by the costs associated with accessibility and the suitability of local characteristics and housing types.

6.4.2 The growth and distribution of strata residences

In recent decades, a combination of strong population growth, shifts in demographic composition and government policies related to urban consolidation have driven changes in land use in Sydney. On average, the Sydney metropolitan area must accommodate an additional 1,800 people each week (ABS 2019), and achieve this within the restrictions imposed by 'urban infill' policies. The difficulty of attaining this goal is compounded by factors that accentuate shortages of accommodation. For example, a trend in metropolitan Sydney towards fewer people per residence generates substantial demand for smaller dwellings. The superimposition of this change on already rapid population growth has led to considerable growth of ARPs across the metropolitan area, and in particular, at higher density rail-accessible locations.

Sydney population, along with the broader NSW, is ageing due to improved life expectancy and the demographic 'bulge' caused by the ‘baby boomer’ generation. As noted, an older population impacts household form, which has become more diverse with fewer individuals per household and increasing the need for more dwellings. In effect, household numbers are increasing faster than the overall population and this has been a consistent trend since 1976 (NSW Environment Protection Authority 2003). For example, between 1996 and 2000 the NSW population grew by 5.5%, but the number of dwellings increased by 9.0%. Couples with dependent children decreased from 44% of households in 1991 to 41% in 2001, while the total number of households with 1–2 people grew by 31%. Since 1996, more than 50% of Sydney households accommodated just one or two residents (ABS 2017). In response, there has been considerable growth in high-rise living. This is indicative of a national trend towards the rising prevalence of apartments in four or more storey blocks (Figure 6.2). This process is accentuated in Sydney where intensification of land use, particularly at the local centre level, is most pronounced amongst the capital cities.

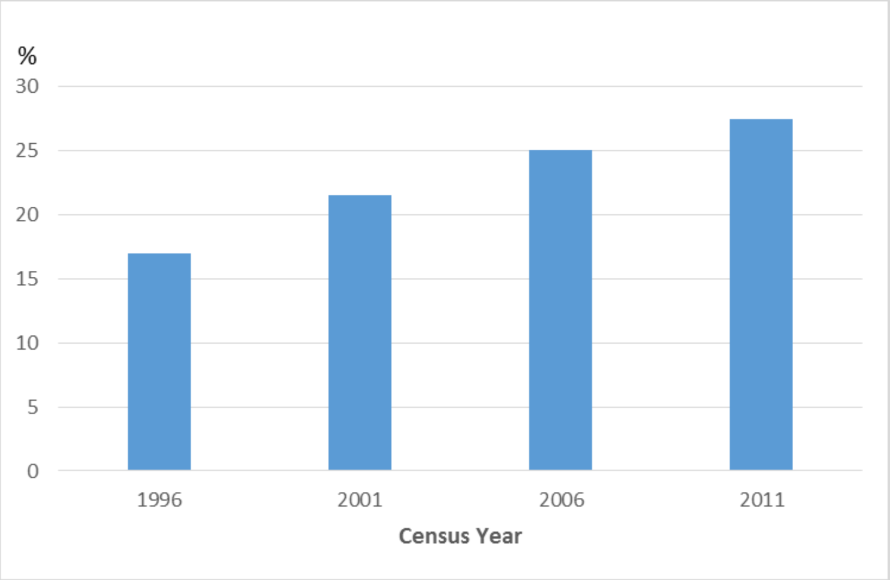
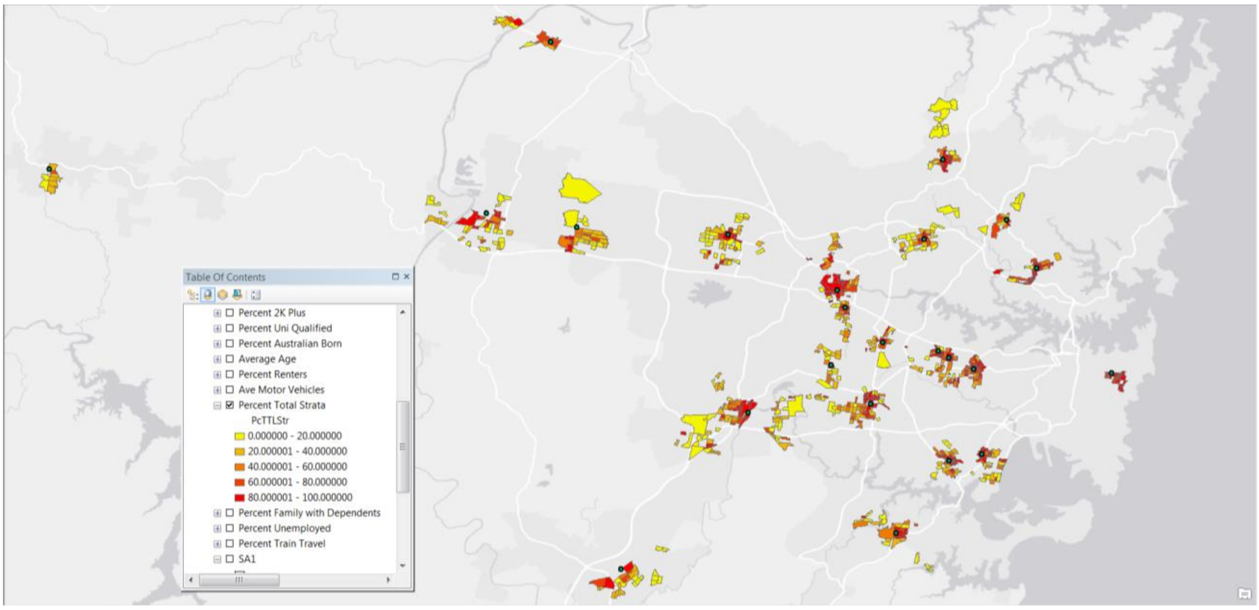


Figure 6.2 Percentage of apartments in a four or more storey block 1996 - 2011 (ABS (2017))

Map 6.2 details the concentration of attached residences at locations nearby rail stations that feature in this study. The results are colour coded to differentiate the intensity of ARP complexes as recorded in 2011. Estimates are based on the percentage of strata units registered for each location at the SA1 level.



Map 6.2 Percentage of ARPs by SA1 (2011)

The above map shows the percentage of APRs is higher closer to the rail stations. This phenomenon typically occurs across the metropolitan area. The pattern that emerges in the map can be attributed to a high demand for residences in rail-accessible zones, which leads to intensification of residential land use at these locations. As described above, the effect is compounded by consistent strong metropolitan population growth and a shift in population age.

6.4.3 Implications of ARP clustering

Dwelling type is likely to have an important role in determining demographic composition. The residential form in the metropolitan area reflects market opportunities and planning policies that facilitate denser housing around public transport hubs/employment centres. Recent ABS analysis[23]suggests a larger concentration of high-density dwellings is likely to attract more young adults and smaller households, often renting. On the other hand, larger detached or separate dwellings, generally located beyond high rail-access zones, are believed more likely to attract families, particularly those with multiple children (ID Consulting 2016).

Since many SA1 neighbourhoods close to rail hubs register 100% ARP occupancy, it is important to explore this relationship further and the implications for neighbourhood demographic profiles. An examination of recent ABS data, particularly relating to apartment living, shows occupancy is more prevalent amongst certain demographic groups, especially those relating to age, family

[23] Analysis of demographic profile in relation to residential type is unavailable for the 2011 census year. 2016 analysis used in this section is likely to be a fair reflection of 2011 circumstances.

structure, income, tenure, origin and motor vehicle ownership. For example, regarding age, ABS data show residents who occupy strata apartments are likely to be considerably younger than the national average (33 years compared with 37.5 years). They also show age groups are unevenly represented in apartment occupancy. By far, the most common age category is 25-34 year-olds who comprise 21% of all people living in apartments (private dwellings). Other significant age groups occupying apartments are those aged between 35-44 (12%), 15-24 years (11%) and 0-4 years (10%). Those least likely to live in apartments are in the 5-14 year bracket (4%) and the 45-54 age bracket (low 7%). However, in regard to the latter, the occupancy rate continues to rise with age until it reaches its maximum at the oldest category (85 plus at nearly 12%) (ABS 2017) . Given the high concentration of strata units nearby rail stations there is an expectation that age patterns at these locations reflect the patterns associated with apartment living.

Life-cycle considerations may also influence the location decisions of families with dependants. The analysis above shows the age group most likely to begin a family (25-34) are common in apartment occupancy. However, older age groups with established families (children aged between 5 and 14) are more likely to occupy single detached dwellings. This confirms the conventional view that areas with a higher proportion of apartments feature younger residents and a smaller proportion of families with older children.

In regard to income, a high concentration of apartments may influence the characteristics of an area. National ABS data indicate the median total income for apartment households is considerably lower than that recorded by households occupying separate dwellings ($1,280 compared with $1,526, ABS 2017). This may be, at least partly, due to the generally younger age profile of apartment dwellers.

National census data also show most apartments are rented (59%) with the remainder owned either outright or with a mortgage. This contrasts with separate dwellings where rental occupancy makes up only 21% (ABS 2017). These observations lead to the expectation that a higher proportion of renters occupy high rail-accessible neighbourhoods compared to neighbourhoods with low rail access.

Analysis of apartment occupation highlights the multicultural aspect of apartment living. ABS data shows that only 6.7% of Australian born people, who occupy private dwellings, live in apartments, while 17% of all overseas born choose this form of accommodation. Apartment living is a relatively new phenomenon in Australian cities, which has historically been dominated by the 'quarter acre block' detached residential housing. In many circumstances apartment living is more aligned with preferences of a growing number of immigrants where occupancy is characterised by unusual tenure longevity. Research shows, this situation is driven by a desire for social connection, which resists the normal pressures and opportunities associated with life-cycle change (Osborne 2012).

The last factor potentially influenced by apartment living is motor vehicle ownership. Recent ABS data suggest that apartment dwellers are less likely to own a motor vehicle. These data show 21% of apartment residents have no car compared with only 4% of residents in separate houses and the overall frequency of motor vehicle ownership is higher for the latter group (ABS 2017). The ABS (2012) reports that people in the 55-65 age bracket are most likely to drive to work or study (78%), while people aged 18-24 are least likely (63%). A younger population occupying apartments and a high concentration of apartments nearby rail hubs leads to the assumption that car ownership is likely to fall with closer proximity to the rail station. However, this is subject to ascertaining more information regarding the extent of average age differences in high rail access neighbourhoods compared to those with low rail access.

6.4.4 Other portrayals of rail induced residential sorting

The previous section reveals a strong relationship between population density and the geographical concentration of apartments. It also provides a useful insight into the demographic patterns that one might expect at rail-accessible locations. This assessment leads to the presumption that households in areas nearby rail stations are predominantly younger, comprise few occupants, are generally poorer, primarily renters, largely overseas born and have lower car ownership than areas farther from rail stations. Indeed, evidence from prior research supports some aspects of this proposition. One study reports that average household size in transit-rich locations has declined in recent years, which is likely a response to changing demographics at these centres (Wang & Woo 2017). This apparent demographic transformation is not inconsistent with qualitative studies that reveal young adults prefer communities that feature greater densification and diversification, which is often associated with transit-rich neighbourhoods (Nielsen Company 2014). Other studies also support the concept that transit-rich neighbourhoods record lower average incomes compared with their surrounding regions (Center for Transit Oriented Development 2014; Lin & Long 2008).

However, conclusions drawn predicting demographic patterns associated with particular residential property types are by nature generalizations and it is feasible some outcomes may differ due to the presence of local moderating factors. For example, Stage 1 results show evidence of a considerable rail induced proximity premium nearby rail stations, which means potentially higher rents that may act as a barrier to poorer prospective residents. Indeed, some studies relating to gentrification indicate that residents nearby transit-rich centres, in fact, are likely to exhibit higher average incomes compared to those without rail access (Barton & Gibbons 2017; Florida et al. 2014; Pollack, Bluestone & Billingham 2010). Rather than assisting the disadvantaged, this has prompted concerns that the development of transit-rich neighbourhoods may lead to displacement of low-income and, perhaps, less ethnically diverse communities.

Until recently, there have been no known studies that investigate multiple variables in relation to rail-accessible neighbourhoods. An attempt to fill this important gap in the literature is offered by McKenzie (2015), who examines the influence of transit systems on the spatial distribution of residents across the Washington metropolitan area. His research explores the extent to which the demographic composition of residents nearby transit stations differs from those in non-transit locations by assessing changes over time. The study also attempts to ascertain the differences in utility derived from rail transit in the urban and suburban environment.

McKenzie employs a descriptive analytical approach. The research shows that rail-accessible neighbourhoods have a higher rate of recent movers than other areas and that in-movers have a strong influence on the demographic profile of transit locations; rail-accessible areas have a higher proportion of younger workers; households without children are more prevalent in rail-accessible neighbourhoods; rail accessibility leads to proportionately more high-income and university educated residents. McKenzie concludes that several socio-economic indicators are similar in Washington DC and the surrounding five counties. In particular, he notes similarities in the distribution of age and educational attainment in these regions. In both cases, young and highly educated adult population disproportionately reside near rail access locations.

The pioneer work of McKenzie provides a solid foundation for further exploration of rail induced residential sorting. However, questions remain how the findings reconcile with other evidence. For example, there is the matter alluded to in Section 6.3, which suggests evidence of a strong relationship between income and rail accessibility is not replicated in Sydney. This may present an unrealistic comparison, but it does, at least, highlight the importance of setting. A key limitation of McKenzie’s research is that it does not adequately control for community differences. Furthermore, there is no regard to context specificity, in particular, consideration of housing costs and how this may expose the vulnerability of some groups. Finally, an important matter neglected in McKenzie’s, and other research, is an understanding of rail station age. Recently constructed stations with nearby neighbourhoods in demographic transition can be expected to produce different outcomes compared with long-standing stations. Such evidence is likely regardless of the methodology used to assess the impact of nearby rail access.

6.5 Summation of concepts Sections 6.2 to 6.4

A lack of consensus and some questionable findings in previous research suggests there is more to the relationship between rail transit accessibility and the sorting of demographic groups than can be interpreted from simple descriptive observations. It is particularly important to appreciate the mechanisms that lead to demographic sorting. In this regard, the three analytical exercises presented in this chapter so far, help clarify some matters that are pertinent to understanding the impact of rail on the spatial patterns of demographic groups. First, Section 6.2 analysis suggests a high degree of consumer utility associated with rail transit, and the perceived benefit is adversely affected by increased distance from the station. This corresponds with the behaviour of the property price premium effect identified in Chapter 5. It can, therefore, be assumed that rail users help underpin price premiums in accessibility zones.

Second, different demographic groups respond differently to rail transit uptake. The results of Section 6.3 show a weak positive correlation between the proportion of train travellers and the concentration of high-income earners and stronger, more significant relationship with university-qualified, professionals, the unemployed and renters. Negative correlations with train travel for the remainder of the demographic variables reveal a weak relationship with the concentration of younger residents, but a relatively strong association with overseas born, families without dependants and (lower) motor vehicle ownership.

Third, Section 6.4 examines contextual factors that may help explain some findings in Section 6.2. Earlier in this study, factors such as price premiums and the size of the commercial complex surrounding rail stations were identified as potential influences on residential sorting at rail-accessible zones. In Section 6.4, the effects of spatial factors such as population density and housing types nearby stations were considered. This reveals that greater population density generally leads to higher concentration of particular residential types that may prove unsuitable for some demographic groups. It suggests that population density is potentially an important contributory factor that may account for some residential sorting nearby rail stations.

This study presumes that residents who occupy neighbourhoods nearby rail stations underpin property price premiums associated with rail access. If some demographic groups have a higher propensity for rail travel than others, we can expect to find evidence of sorting in areas associated with high rail access. Particular groups concentrated in these areas are likely to have a common interest in residing nearby rail access and/or the services that arise in the precinct of the rail hub. They are also likely to be undeterred by life-cycle constraints and have a willingness to pay the premiums associated with such neighbourhoods. The following section is designed to determine if the commonality of residents who occupy high rail accessibility zones manifests itself in concentrations of particular demographic groups.

6.6 Rail access and local demographic patterns

This section addresses the limitations of the exiguous prior research in this field by assessing how neighbourhoods with high rail accessibility predict variations in the concentration of demographic groups. The analytical approach employs cross-sectional regressions to determine if variables such as income, place of birth, family structures etc. are spatially dependent. This enables identification of statistically significant clusters of these variables in neighbourhoods that have various degrees of rail accessibility.

Barton and Gibbons (2017) in their recent article published in Urban Studies provide an important precedent for the analytical approach taken in this study. These authors demonstrate how high-income households, as a dependent variable, respond to variations in the concentration of rail and bus transit stops in New York. Barton and Gibbons' study highlights the fact that the effect of rail accessibility is not simply limited to property price variations, but that it may also influence demographic patterns. The latter suggests there is a utility factor associated with rail transit that may influence the settlement of some demographic groups. This means there are potentially two forces in play at neighbourhoods nearby rail stations. On the one hand, there is the positive attraction of access to the cost and time saving benefits associated with rail transit. On the other hand, there is the negative impact of price premiums in high rail access areas which, in effect, impose financial barriers and, therefore, entry level standards at these locations. For the purpose of this study, these effects are considered the positive and negative externalities generated by rail transit. It should be noted that these concepts are very likely interrelated, which means price premiums nearby rail stations influence the nature of residential sorting and vice versa

While the inclusion of income as a dependent variable is supportive of the approach taken in the present study the overall research strategy differs from Barton and Gibbons' study. For example, a point of difference is the nature of the study area. The authors investigate a city where the density of rail transit is particularly high across the metropolitan area and changes to demographic profile corresponding to changes in distance from rail access points are not easily detected. Instead, the authors explore neighbourhood differences due to local concentrations of public transit. In the present study, the analysis considers a city with a lower density of rail stops, enough to allow investigation of changing demographic patterns in response to rail proximity. Another point of difference is that the present study examines a variety of demographic variables. This means the concept of income distribution, treated as a dependent variable, is extrapolated to a larger set of demographic variables. This is designed to add rich contextual information available from a broad investigation of local demographic profiles as they relate to rail access.

6.6.1 Analytical procedure

In order to demonstrate the relationship between the pattern of settlement and rail accessibility it is necessary to show how demographic groups respond to rail station proximity. In the present study, rail induced property premiums are considered a reflection of the cost/benefit attached to residential space nearby rail transit. The magnitude of these premiums is an indication of the extent of value attributed to the amenity. In this research, both the utility and price effect are assumed implicit in the zone variables and the residential decisions of home-seekers are expected to take these factors into account. The extent to which particular demographic groups are influenced by the utility and/or property premiums associated with rail access should be reflected in the way that concentration of these groups corresponds to the pattern that emerges from Stage 1 results.

There are two parts to Stage 2 analysis. The first part examines the overall distribution of each demographic variable to determine if it is weighted more heavily in the rail-accessible neighbourhoods compared to neighbourhoods with limited rail access. The second part examines spatial patterns of the demographic variables in more detail. It involves a test to determine if demographic patterns align with the behaviour of property price premiums identified in Stage 1 results. In this exercise, the influence of individual accessibility zones is assessed along with other factors that affect the cost/benefit associated with particular locations.

In this study, the dependent (demographic) variable is examined at the SA1 level. This research uses the same SA1s observations included in Stage 1 analysis. This means some SA1s are missing from the data set leaving occasional gaps when mapping the demographic variables. However, the data aligns well with the research conducted in Chapter 5, which includes only observations that can be identified within the influence of particular rail access points. The pertinent independent variables are predictors drawn from Stage 1 modelling, except for the way waterside locations are treated. For the purpose of this research, the continuous variable $\ln(RBW)$ replaces $WTRSIDE$

which offers a strategically superior approach to account for differences in the dependent variables (see Section 5.4.2).[24] The criteria for establishing a relationship between the pattern of property price premiums found in Stage 1 and the concentration of demographic variables in Stage 2 research are explained in the following section.

6.6.2 Criteria

Two criteria are proposed to test the relationship between neighbourhood demographic patterns and nearby rail access. These are as follows:

Part 1 criterion

This exercise determines if a demographic group (or its opposite) has, on average across the metropolitan region, a significantly larger concentration (at the .01 Level) in the combined high rail-access *ZONE1, 2, 3* and *4*, (*GZ1234*) compared with low rail-access *ZONE5*. If so, this is described as a dominant group and the effect of high rail accessibility zones on this group is considered *positive*. In this case, group members are disproportionately affected by, or influence the property price premiums associated with rail access. Only dominant groups are considered in Part 2 analysis.

Part 2 criterion

This part of the analytical process determines the existence of two additional conditions that provide evidence of a nexus between rail-accessibility and demographic groups. First, after controlling for the size of the commercial complex and population density in neighbourhoods with high rail access, a demographic group will, on average across the metropolitan region, have a significantly larger concentration in each of the first three high rail-accessible zones *ZONE1, 2* and *3* (at the .01 level)[25], compared with low rail-accessible *ZONE5*. Second, the concentration of a demographic group in *ZONE2, 3, and 4* either diminishes or increases[26] with distance from the

[24] An important point to note is that concentrations of any particular demographic variables are not restricted to locations with rail access. Rather, the approach taken in this study aims to identify neighbourhoods where proximity to rail stations produces a bias in the concentration of the demographic variable. The following subsection reveals how this might be assessed.

[25] In these studies, households found in areas equivalent to *ZONE4* are often found marginal in terms of their significance and may even produce the opposite sign.

[26] In the case of the demographic group's opposite.

station[27]. Meeting both these conditions indicates a *strong* effect of rail induced residential sorting. This suggests a demographic group's willingness to pay for accessibility to a rail station proximity is due either to the positive utility provided by rail transit or of the negative costs it incurs.

This dual test is useful for two reasons. First, it demonstrates the impact of rail accessibility on the overall concentration of demographic features in rail transit neighbourhoods. Second, it identifies the change in the pattern of concentration that occurs with greater distance to the station. In addition, a variety of other factors considered in modelling this condition improves our understanding of contextual matters that potentially modify the impact of rail transit.

Essentially, this approach attempts to match the behaviour of property premiums against the concentration of demographic characteristics at the zonal level. This zonal emphasis provides greater flexibility in analysing the relationship between the two variables than is otherwise the case using a continuous distance variable, particularly due to the non-linearity imposed by *ZONE1*. The zonal approach also facilitates understanding the spatial relationship between the two variables by enabling analysis of zonal/district differences.

In this study, the criteria noted above are particularly important as they reveal the crucial link between residential sorting and rail access. Two conditions are required to confirm this relationship. First, the overall concentration of a demographic variable in rail accessible zones must prove both *positive* and *strong*. Second, the rail-accessible coefficients in Part 1 and *ZONE1, 2,* and *3* in Part 2 must return the same sign[28]. These conditions form the basis for later discussions relating to the research questions and hypotheses associated with Stage 2 research.

6.6.3 The relationship between the concentration of demographic variables and rail accessibility

This section applies the criteria outlined above to test the relationship between demographic variables and rail accessibility. The analysis classifies the demographic variables into four categories. The first category comprises income alone, which is considered particularly important in the limited extant literature. The second category of variables relates to educational attainment

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[27] *ZONE1* is excluded from this requirement. Stage 1 results reveal residents in *ZONE1* derive disproportionate negative externalities due to very close proximity to rail stations, which may similarly affect the concentration of some demographic groups in that zone.

[28] The consistent signs of the aggregate rail-accessible zone (Part 1) and *ZONE1, 2, 3* are of greatest importance. The sign of *ZONE4* may differ to the others in Part 2. The sign and magnitude of the *ZONE4* may determine if the hypothesis is accepted or rejected.

and employment, which are often thought to have a close relationship with income. The third category comprise variables relating to origin of residents and life-cycle matters. The final category is motor vehicle ownership relating to life-style.

6.6.3.1 Income

Part 1 exercise tests the spatial relationship between the distribution of high-income households and rail accessibility according to the aforementioned criteria. Univariate analysis is used to assess spatial dependency. The simple equation used for Part 1 analysis is calibrated as follows:

$$PC2KPLUS = f(GZ1234) \qquad (6.2)$$

where:

$GZ1234$ is the aggregate effect of the rail accessibility zones.

The estimated coefficient results for the income variable reveals there is no significant difference between *GZ1234* and the base case *ZONE5*. These estimates show a *p*-value of .280, which means the behaviour of observations does not satisfy the first criterion. This suggests a lack of relationship between the combined high rail-accessible zones and *Pc2KPLUS* and reconfirms the independence of these variables, both of which appear on the right-hand side of the HPM equation in Stage 1 analysis.

6.6.3.2 Education, profession and unemployment

This section investigates the spatial distribution of residents based on education and employment status. Again, the results of Part 1 and 2 analyses are assessed in relation to the criteria established in Section 6.6.2. Part 1 estimates the change in the aggregate high rail-assess areas compared to those areas with low rail access. Part 2 analysis examines the response of each variable to individual rail access zones and other geographical factors.

Part 1 analysis

Table 6.4 shows coefficients for GZ1234, with education and work-related factors as the dependent variables, each have positive signs and are significant. This suggests that university-qualified, professionals and the unemployed are disproportionately represented in rail-accessible zones. The effect is most pronounced in the case of university-qualified residents where the proportion is 8.828 percentage points greater in *GZ1234* compared to *ZONE5* (mean value 21.586). Professionals have a 2.21 percentage point larger concentration in the high rail-accessible area (mean 11.43) and unemployment is overrepresented by 1.039 percentage points (mean 4.77). The coefficient signs are consistent with the results of Section 6.3, which estimates the correlation between rail travel and the dispersion of demographic groups.

Variable	Mean	SD	coefficient	*t*-value	Sig
PcUNIQL	21.586	11.188	8.828	12.256	.000
PcPROF	11.428	5.577	2.207	5.854	.000
PcUEMP	4.772	2.092	1.039	7.412	.000

Table 6.4 Coefficients for *GZ1234* with educational and work related factors as the dependent variables.

Part 2 analysis

Multivariate regression is used for Part 2 analysis. This is designed to examine the relationship between the demographic characteristics and accessibility features as well as other spatial factors. The equation, specified below, takes into account important considerations raised in Sections 5.3, 5.4.2, and 6.4.

$$PcUNIQL/PcPROF/PcUNEMP = f(Z1234, PARKING, LINES, \ln(MW), SA1POPDN, SEMPLOY, \ln(RBW), SOUTH, WESTCEN, WEST, SOUWEST, NORTH) \quad (6.3)$$

Estimations for each variable, based on robust standard errors, are shown in Table 6.5.

	PcUNIQL		*PcPROF*		*PcUEMP*	
	β	*t*	β	*t*	β	*t*
(Constant)	12.429	3.834	4.747	2.805	5.232	5.445
ZONE1	6.608	6.128	-0.002	-0.003	1.851	4.615
ZONE2	7.551	12.970	1.227	3.694	1.310	6.495
ZONE3	5.801	10.560	1.040	3.539	1.022	6.116
ZONE4	1.876	4.239	0.128	0.499	0.518	3.228
PARKING	-1.969	-4.575	0.248	0.990	-0.242	-1.533
LINES	0.773	5.349	0.499	6.387	-0.164	-3.074
ln*(MW)*	1.190	3.662	1.370	8.197	-0.492	-4.881
SA1POPDN	181.079	4.161	10.483	0.755	48.243	4.997
SEMPLOY	0.000	12.520	0.000	12.790	-0.000	-0.084
ln*(RBW)*	-0.370	-1.618	-0.508	-3.621	0.24	3.841
SOUTH	-5.601	-8.592	-4.080	-11.080	0.279	2.290
WESTCEN	-13.664	-21.770	-8.923	-24.060	1.651	7.008
WEST	-15.132	-19.410	-8.103	-17.650	0.813	2.807
SOUWEST	-18.307	-26.560	-9.984	-23.270	1.305	5.356
NORTH	3.663	4.779	2.555	5.527	-0.266	-1.160
R^2	0.767		0.692		0.206	
Adjusted R^2	0.764		0.687		0.195	
$F(15, 1090)$	261.444		153.241		22.597	
P- value *(F)*	.000		.000		.000	

Table 6.5 Coefficients of predictors with *PcUNIQL, PcPROF* and *PcUEMP* as the dependent variables

Following is a brief appraisal of the results for variables *PcUNIQL, PcPROF and PcUEmp.*

Educational attainment variable (PcUNIQL)

Table 6.5 shows the predictive variables account for 76.4% of the spatial distribution of university-qualified residents. The sign of the coefficients for the individual rail-accessible zones is positive and aligns with Part 1 analysis. In Part 2 analysis, the inclusion of control variables moderates the average impact of rail access. Nevertheless, the coefficients for *ZONE1, 2, 3 and 4* remain large. This is especially evident when considering the mean concentration of the *PcUNIQL* variable.

Regarding other predictor variables, *t*-values highlight the importance of metropolitan districts. The district within which zone coefficient estimates are made influences the magnitude of this response. Similar to residents' income, the results suggest those with university qualifications are less inclined to live in western metropolitan districts than eastern districts.

Table 6.6 below clarifies how zone coefficients vary across the Sydney metropolitan area. This table takes the form of a matrix, which is a representative case showing proportions of university-qualified settlement according to zone and district. Matrix estimates are based on the availability of parking (*PARKING*); and the average number of rail lines servicing stations (*LINES*), distance from the motorway (ln*(MW)*), population density (*SA1POPDN*), suburban employment (*SEMPLOY*) and distance to the nearest recreational body of water (ln*(RBW)*), all adjusted for their respective coefficients. The table shows absolute percentage values and the districts are ordered according to descending values.

	NORTH	***CENTRAL***	***SOUTH***	***WESTCEN***	***WEST***	***SOUWEST***
ZONE1	30.67	26.97	21.37	13.31	11.83	8.66
ZONE2	31.62	27.92	22.32	14.26	12.78	9.61
ZONE3	29.87	26.17	20.57	12.51	11.03	7.68
ZONE4	25.87	22.17	16.57	8.51	7.03	3.86
ZONE5	24.07	20.37	14.77	6.71	5.23	2.06

Table 6.6 Coefficient matrix with *PcUNIQL* as the dependent variable

Table 6.6 clearly demonstrates the magnitude of difference in the concentration of university-qualified residents across districts and zones. This conflation of zone and district estimates shows the highest concentrations of this group are found in *NORTH*, *CENTRAL* and *SOUTH*. However, the relatively small number of university qualified in the western sector (*WESTCEN*, *WEST* and *SOUWEST*) dramatically reduces the magnitude of the concentration of this demographic group in the accessibility zones.

Zone coefficients provided in Table 6.5 determine the slope of the relationship between distance to the rail station and the concentration of university-qualified, for all districts. As mentioned above, the signs of coefficients for *ZONE1*, *2*, *3* and *4* are all positive and each significant. Replicating the results presented in Chapter 5, the largest coefficient registered in *ZONE2* and this diminishes with increased distance from the station. The finding supports the postulate of rail access utility, which suggests the value derived from rail transit varies with proximity to the station.

Proportion of professionals (PcPROF)

Part 2 modelling for the distribution of professionals finds the predictive variables account for 69.2% of the spatial diversity. Estimated standardized coefficients (not shown) again highlight the importance of the metropolitan district. In line with the results for income and educational attainment, professionals prefer neighbourhoods in the South, Central and North compared with other more remote districts. Both professionals and university-qualified have in common a tendency to live nearby stations with a higher number of train lines, farther from motorway access and in areas with higher levels of suburb employment.

Although there is a positive weighting of professionals in the combined rail-accessible area (Part 1) the individual zone results show this is distinctly not the case for residences closest to the rail station. *ZONE2, 3 and 4* coefficients are positive and diminish with greater distance from the station. However, *ZONE1* has a negative weighting and both *ZONE1* and *ZONE4* are not significant. Overall the sorting pattern of professionals is not consistent in response to the positive externalities derived from access to rail.

Unemployment variable (PcUEMP)

Unlike the substantial adjusted R^2 value recorded for other models in this segment *PcUEMP* registers a modest 0.21. Following the results of Part 1 analysis, the sign of each rail-accessible zone coefficient in Part 2 is estimated to be positive and significant. Also, the rail-accessible zone coefficients diminish in value with greater distance from the station. These results suggest that rail travel is an important service for the unemployed and support the notion that, for many in this category, the cost of alternative car transport may be an impediment to residing in communities with poor rail access.

	WESTCEN	***SOUWEST***	***WEST***	***SOUTH***	***CENTRAL***	***NORTH***
ZONE1	6.38	6.03	5.54	5.00	4.73	4.46
ZONE2	5.84	5.49	5.00	4.46	4.19	3.92
ZONE3	5.55	5.20	4.71	4.17	3.90	3.63
ZONE4	5.05	4.70	4.21	3.67	3.40	3.13
ZONE5	4.53	4.18	3.69	3.15	2.88	2.61

Table 6.7 Coefficient matrix with *PcUEmp* as the dependent variable

Regarding the metropolitan districts, the spatial distribution of *PcUEMP* is contrary to the pattern encountered in the case of income, educational attainment and professionals. Table 6.7[29] shows *PcUEMP* at *WESTCEN*, *SOUWEST* and *WEST* have relatively higher concentrations compared

[29] This is a representative case showing proportions of unemployed based on binary variable *PARKING coded 1;* and average *LINES*, *ln(MW)*, *SA1POPDN*, *SEMPLOY* and *ln(RBW)* adjusted for their respective coefficients.

with the eastern districts. Again, this is intuitively correct considering the lower value of residences in these areas (see Stage 1 results). The highest relative concentration is found in *WESTCEN*, which has, overall, potentially larger employment opportunities than the *WEST* and *SOUTH WEST*.

6.6.3.3 Age, Australian born, families with dependants and renters

This section examines the spatial distribution of residents in relation to life cycle and birth status factors. Pertinent variables are average age, Australian born, families with dependants and renters. Following the procedure set out in the last section the results of Part 1 and 2 analyses are assessed in relation to the criteria established in Section 6.6.2. In the first instance, the results presented in Table 6.8 show the change in the concentration of demographic groups in the aggregate rail-assessable areas compared to areas of low rail access. This is followed by Table 6.9 which shows the settlement pattern of each demographic group in relation to rail access zones as well as other accessibility and geographical factors.

Part 1 analysis

Variable	**Mean**	**SD**	**Coefficient**	***t*-value**	**Sig**
AVAGE	36.18	5.18	-0.55	-1.56	0.120
PcAUSB	48.20	19.43	-20.86	-17.72	0.000
PcFAMDEP	30.99	10.46	-6.99	-10.18	0.000
PcRENTER	43.59	18.37	19.63	17.63	0.000

Table 6.8 Coefficients for *GZ1234* with *AVAGE, PcFAMDEP, PcAUSB* and *RENTERS* as the dependent variable.

Table 6.8 shows the mean and standard deviation for the dependent variables *AVAGE*, *PcAUSB*, *PcFAMDEP* and *PcRENTER* together with *GZ1234* coefficients. The results indicate a negative coefficient sign for *AVAGE*, which conforms to findings in Section 6.3. However, the estimated coefficient for *AVAGE* is noticeably small and is not significant at any level. The results also suggest there are disproportionately more Australian born and families with dependants in neighbourhoods with low rail access and there are more renters in high rail access zones. Rail-accessible zones have the greatest impact on *PcAUSB* and *PcRENTER* relative to the average concentration of these demographic characteristics. The results indicate there are 20.86% fewer Australian born and 19.63% more renters at locations with high rail access.

Part 2 analysis

The multivariate regression equation (6.4) is employed in this section. Estimates for *AVAGE* are not shown as this variable does not satisfy the test for Part 1 criteria. For the remaining variables, this exercise reveals the relationship between the demographic characteristics and the individual accessibility zones as well as other accessibility and spatial factors. The equation is specified as follows:

$$PCAUSTB/PCFAMDEP/PCRENTER = f(ZONE1234, PARKING, LINES, \ln(MW), SA1POPDN, SEMPLOY, \ln(RBW), SOUTH, WESTCEN, WEST, SOUWEST, NORTH \quad (6.4)$$

Estimations of each coefficient variable, based on robust standard errors, are shown in Table 6.9.

	PcAUSB		***PcFAMDEP***		***PcRENTER***	
	β	***t***	**β**	***t***	**β**	***t***
(Constant)	-7.25	-1.02	43.08	9.34	41.99	5.30
ZONE1	-24.34	-11.97	-11.01	-8.77	30.14	12.70
ZONE2	-19.85	-16.32	-9.60	-11.00	24.27	15.95
ZONE3	-15.08	-13.89	-7.35	-9.36	20.33	14.87
ZONE4	-7.33	-7.90	-4.52	-6.13	11.85	9.70
PARKING	10.94	11.26	-2.75	-3.81	1.74	1.60
LINES	0.66	2.31	-0.94	-4.20	-0.43	-1.11
ln*(MW)*	8.54	13.81	-2.13	-4.43	-2.21	-2.81
SA1POPDN	-608.90	-6.10	-58.26	-1.81	611.60	5.32
SEMPLOY	6.78e-05	1.40	-0.00	-11.11	0.00	7.59
ln*(RBW)*	-0.43	-0.95	1.37	3.56	-0.22	-0.37
SOUTH	-5.87	-4.45	8.01	8.04	-8.55	-5.76
WESTCEN	-11.65	-8.70	15.91	15.41	-4.02	-2.50
WEST	10.40	6.41	0.94	0.74	3.88	1.78
SOUWEST	-5.29	-3.55	10.58	9.58	4.07	2.21
NORTH	-2.51	-1.63	8.54	8.02	-10.10	-6.06
R^2	.71		.39		.47	
Adjusted R^2	.70		.38		.46	
$F(15,\ 1090)$	197.07		47.21		65.84	
P-value (*F*)	1.6e-297		2.7e-107		5.8e-141	

Table 6.9 Coefficients of predictors with *PcAUSB, PcFAMDEP and PcRENTER* as the dependent variables.

Following is a brief discussion of the results for each variable:

Average age variable (AVAGE)

As mentioned, the variable *AVAGE* does not satisfy Part 1 criteria and therefore Part 2 analysis is unnecessary. However, it is worthy of note that the combined effect of all variables included in the model account for only a small proportion of age distribution and that average age appears reasonably evenly distributed amongst the districts. These points and others relating to age distribution are discussed further in Chapter 7.

Australian born variable (PcAUSB)

In this case, the predictive variables have a substantial impact on the dependent variable (accounting for 70.6% of the variation in *PcAUSB*). The signs in Part 2 of the coefficients for each zone correspond with Part 1 analysis and are significant. The magnitude of impact on the *PcAUSB* variable also grows with closer proximity to the station, which effectively means there is an increasing proportion of non-Australian born. The strength of the relationship with rail access is clearly demonstrated by the fact that non-Australian born are undeterred by the negative externalities associated with very close proximity to the station (*ZONE1*).

The standardized coefficient [30] identifies rail-accessibility as a major contributor to the concentration of non-Australian born residents. It also supports the idea that immigrants generally value public transport more than Australian born residents (Section 6.3). Both these factors contribute significantly to the spatial distribution of immigrants.

	WEST	*CENTRAL*	*NORTH*	*SOUWEST*	*SOUTH*	*WESTCEN*
ZONE1	53.50	43.10	40.59	37.81	37.23	31.45
ZONE2	57.99	47.59	45.08	42.30	41.72	35.94
ZONE3	62.76	52.36	49.85	47.07	46.49	40.71
ZONE4	70.51	60.11	57.60	54.82	54.24	48.46
ZONE5	77.84	67.44	64.93	62.15	61.57	55.79

Table 6.10 Coefficient matrix with *PcAUSB* as the dependent variable[31]

Another geographical factor that influences the location decisions of non-Australian born residents is population density which, in turn, is positively related to strata concentration (Section 6.4.3). In this case the factor coefficient is negative and significant.[32] This suggests that larger concentrations

[30] See Appendix C for standardized coefficients.

[31] Note: *Constant* is not significantly different from zero. *NORTH* is not significantly different from *CENTRAL*.

[32] A large coefficient is due to small observed values. *SA1POPDN* is measured in terms of sq. metres.

of Australian born are found in areas with lower population density and therefore the converse is true for immigrants. On the other hand, from a district perspective there appears to be little evidence of east/west differentiation, which is common to other demographic groups. The highest concentration of non-Australian born is located in the *WESTCEN* district (Table 6.11).

Families with dependants (PcFAMDEP)

Part 1 analysis indicates the coefficient for *GZ1234* has a negative sign and is significant which means families without dependants are more likely to occupy rail-accessible neighbourhoods than neighbourhoods without rail access. Likewise, Part 2 results show that the individual rail-accessible zones have a negative coefficient and are highly significant. There is also evidence that the concentration of families without dependants increases with reduced distance from the station and this group is more inclined to live near rail stations with parking and a larger selection of rail lines.

	WESTCEN	*SOUWEST*	*NORTH*	*SOUTH*	*WEST*	*CENTRAL*
ZONE1	47.98	42.65	40.61	40.08	33.01	32.07
ZONE2	49.39	44.06	42.02	41.49	34.42	33.38
ZONE3	51.61	46.31	44.27	43.74	36.67	35.73
ZONE4	54.47	49.14	47.10	46.57	39.50	38.56
ZONE5	58.99	53.66	51.62	51.09	44.02	43.08

Table 6.11 Coefficient matrix with *PcFAMDEP* as the dependent variable[33]

The difference in the prevalence of families with children between geographies is also noticeable in the distribution amongst metropolitan districts. The magnitude of families with dependants across metropolitan districts is shown in Table 6.11. Apart from *WEST*, which is not significant, there appears to be a preference for households with dependent children to locate outside the *CENTRAL* district. This is not surprising given the fact that a unit of land size is relatively more expensive in the latter district. The theme concerning sensitivity to the residential property cost is also reflected in the lack of *SA1POPDN* significance, which implies that property cost rather than space is the dominant driver behind family sorting.

[33] Note: *WEST* is not significantly different from *CENTRAL*.

Renters (*PcRENTER*)

Similar to non-Australian born, renters in Part 1 analysis shows strong evidence of spatial dependency. In Part 2 analysis, the sign of the *PcRENTER* coefficients is positive for each zone and the magnitude diminishes with distance from the rail station. Again, similar to the results for non-Australian born, the concentration of renters grows progressively all the way to the station. In addition, the growing concentration is strongly aligned with zones despite the competing influence of *SA1POPDN*.

	SOUWEST	*WEST*	*CENTRAL*	*WESTCEN*	*SOUTH*	*NORTH*
ZONE1	76.21	76.02	72.14	68.12	63.59	62.04
ZONE2	70.33	70.14	66.26	62.24	57.71	56.16
ZONE3	66.39	66.20	62.32	58.30	53.77	52.22
ZONE4	57.91	57.72	53.84	49.82	45.29	43.74
ZONE5	46.06	45.87	41.99	37.97	33.44	31.89

Table 6.12 Coefficient matrix with *PcRENTER* as the dependent variable[34]

The broader geographical differences are also notable. The matrix in Table 6.12 shows the interaction of zone and district variables and reflects the degree of renter rail accessibility across the metropolitan area. This reveals that renters are more likely concentrated in *SOUWEST and WEST* districts than in *SOUTH* and *NORTH* where house prices, and therefore rents, are higher (see Stage 1 results, Section 5.4). *CENTRAL and WESTCEN* provide the middle range districts. The high rate of renter concentration in *CENTRAL*, where rents are also relatively high, is probably due to the large concentration of jobs in this district. While metropolitan districts are influential, standardized coefficients[35] suggest that rail-accessible zones have relatively far greater impact on renter distribution.

6.6.3.4 Motor vehicle ownership

Finally, this section examines the life-style characteristic concerning motor vehicle ownership and, in particular, the influence location has on household vehicle numbers. Part 1 analysis shows the change in the aggregate rail-accessible areas in relation to localities with low rail access. *Part 2* then shows how motor vehicle ownership is influenced by various accessibility and geographical factors. Again, the results of Part 1 and Part 2 analysis are assessed in relation to the criteria established in Section 6.6.2 to determine the validity of the hypothesis (Section 3.3).

[34] Note: *WEST* is significant at the .10 level

[35] See Appendix C.

Part 1 analysis

Variable	Mean	SD	Coefficient	*t*-value	Sig
$AVMVOWN$	1.256	0.362	-0.487	-24.32	0.000

Table 6.13 Coefficients for *GZ1234* with *AVMVOWN* as the dependent variable

Table 6.13 shows the univariate regression estimates for coefficient *GZ1234*. Here, the sign of the coefficient is negative and highly significant. The results estimate that average motor vehicle ownership is considerably lower (48.74 percentage points) in high rail-accessible neighbourhoods compared to neighbourhoods with low rail access. This result is entirely consistent with Section 6.3, which highlights the contrary direction of car ownership and rail usage. The *t*-value is also the largest recorded for all Part 1 analyses in this research and this variable alone accounts for approximately 34.83% of the variation relating to motor vehicle ownership. These results suggest location, particularly in relation to rail accessibility, has a substantial influence on average motor vehicle ownership.

Part 2 analysis

Again, a multivariate regression equation is employed in this section. This examines the relationship between motor vehicle ownership and the individual accessibility zones as well as other accessibility and spatial factors. The equation is specified as follows:

$$AVMVOWN = f(ZONE1234, PARKING, LINES, \ln(MW), SA1POPDN, SEMPLOY, \ln(RBW), SOUTH, WESTCEN, WEST, SOUWEST, NORTH) \quad (6.5)$$

Estimations from the regression analysis are shown in Table 6.14.

Variable	**Coefficient**	**Std error**	***t*-value**	**Sig**
(Constant)	1.35	0.147	9.23	.000
ZONE1	-0.63	0.034	-18.68	.000
ZONE2	-0.55	0.026	-21.38	.000
ZONE3	-0.47	0.024	-19.63	.000
ZONE4	-0.28	0.022	-12.76	.000
PARKING	-0.00	0.020	-0.05	.957
LINES	0.01	0.006	1.76	.078
ln*(MW)*	0.03	0.015	2.04	.041
SA1POPDN	-11.00	2.035	-5.41	.000
SEMPLOY	-8.86e-06	1.01e-06	-8.76	.000
ln*(RBW)*	-0.00	0.011	-0.20	.843
SOUTH	0.16	0.028	5.82	.000
WESTCEN	0.25	0.028	8.90	.000
WEST	0.11	0.038	3.00	.000
SOUWEST	0.15	0.032	4.57	.000
NORTH	0.21	0.030	7.02	.000
R^2	0.594	Adjusted R^2	0.588	
$F(15, 1090)$	107.540	*P*-Value (*F*)	.3e-202	

Table 6.14 Coefficients of predictors with *AVMVOWN* as the dependent variable

The variables included in Table 6.14 explain 58.83% of the variation observed in *AVMVOWN*. All rail-accessible zone variables have a negative sign and are significant. There is clear evidence of diminishing average motor vehicle ownership as one moves closer to the rail station. The standardized beta[36] suggests the rail-accessible zones are overwhelmingly important amongst the set of predictive variables used in this analysis.

Other factors of note are *SEMPLOY*, *SA1POPDN* and the metropolitan districts. The coefficient result for *SEMPLOY* aligns with the notion that neighbourhoods in suburbs with larger sized commercial complexes are likely to have lower car ownership than those with smaller adjoining complexes. Greater density generally means more public transportation options, including more abundant bus stops. This reduces the need for motor vehicle ownership. Consistent with this is the estimated lower motor vehicle ownership in the Central district where the density of population is relatively higher than in the other metropolitan districts (Section 6.4.1). A matrix, taking in to account the district motor vehicle ownership based on zone averages, is shown in Table 6.15.

[36] Not shown.

	WESTCEN	*NORTH*	*SOUTH*	*SOUWEST*	*WEST*	*CENTRAL*
ZONE1	0.97	0.93	0.88	0.87	0.84	0.72
ZONE2	1.05	1.01	0.96	0.95	0.92	0.80
ZONE3	1.13	1.09	1.04	1.03	1.00	0.88
ZONE4	1.32	1.28	1.23	1.22	1.19	1.07
ZONE5	1.60	1.56	1.51	1.50	1.47	1.35

Table 6.15 Coefficient matrix with *AVMVOWN* as the dependent variable

It is important to note that the impact of the various demographic groups on motor vehicle ownership in high rail-accessible areas is subject to the degree of their concentration at these locations. This, in turn, is influenced by the perceived value that demographic groups place on proximity to rail transit. Ultimately, it is the reaction of demographic groups to the positive and negative externalities associated with rail-accessibility that lead to these patterns. Further discussion on these matters is presented in Chapter 7.

6.7 Summary

This chapter attempts to estimate and explain the differences in the concentration of demographic groups at neighbourhoods with nearby rail access compared to other neighbourhoods. Section 6.6.2 introduced the criteria used to establish whether population sorting is associated with externalities due to rail transit. The analytical exercise employed to test the criteria estimates the sign, significance and magnitude of coefficients representing the demographic factors. Controlling for population density and the size of the surrounding commercial district the results indicate that rail accessibility may influence some residential sorting. In particular, areas with high rail-accessibility tend to have a higher concentration of university-qualified, unemployed, overseas born, families without dependants and renters. High rail-accessible neighbourhoods are also likely to attract demographic groups that have lower motor vehicle ownership, compared to areas with low rail access. The implications of these results for planners, community groups, developers and academics whose interests lie in understanding the impact of rail transit are addressed as part of the discussion in the following chapter.

7 Discussion of Research Findings and Implications for Stakeholders

This dissertation sets out to determine the existence of rail induced residential property premiums at locations across the Sydney metropolitan district and to reveal how, and to what extent, rail accessibility predicts the spatial distribution of demographic groups. The research involves two principal investigative processes. The first deals with determining the relationship between property values and rail accessibility and the second examines the relationship between rail accessibility and neighbourhood demographic characteristics. This chapter reviews the processes and results of the investigation before discussing the findings in relation to the research goals and exploring the implications of the research.

7.1 Stage 1: rail induced property price premiums

In relation to Stage 1 research, the following discussion is arranged in four parts. It begins with a brief review of the analytical procedures used in the study. This is designed to augment understanding of some important concepts that lead to the research findings (Section 7.1.1). The next part is a summary of the empirical results and a discussion concerning how these results address the research questions and hypotheses (Section 7.1.2). Finally, the discussion considers the implications of research outcomes for policymakers, urban planners, businesses and other relevant stakeholders (Sections 7.1.3 and 4).

7.1.1 Stage 1 analytical technique

The first phase of Stage 1 employs a multivariate HPM to estimate the effect of rail accessibility on house prices. The technique is considered a 'global' model, which effectively disaggregates properties into their constituent characteristics. By controlling for a range of structural, accessibility and neighbourhood characteristics, this researcher is able to isolate and estimate rail induced residential property price premiums. The data set contains property details of 11,912 residential unit market sale transactions at, or close to, the census year 2011. The database has been carefully constructed so that the observations include only those for which the target station is also the nearest station. This produces a corridor of observations, the shape of which is determined by the unique influence of the target station. These data are then classified into five distinct geographical zones surrounding each station. Inner zones one to four are considered areas of high rail accessibility, from a distance perspective, although accessibility diminishes with greater distance from the station. Zone five is considered a low accessibility zone and is unlikely to attract train users as their first mode of transport.

Stage 1 analytical procedure is designed to estimate the impact of high accessibility zones on property prices after controlling for other factors known to have this effect. A notable deficiency of prior research, in this field, is the lack of an attempt to adequately capture the effect of the commercial district (*place*) surrounding transit locations. This is important in order to isolate the housing price premiums associated with changing proximity to rail access from the effect of commercial and public services located nearby rail stations. In this research, the latter factor is represented by local employment, which acts as a proxy to account for different sized commercial districts.

Another innovation applied in this research is the use of GWR. This technique considers spatial variation of land value drivers. It incorporates spatial coordinates in the traditional global HPM to provide estimates of variations in land value over space. This reveals patterns of rail induced proximity premiums at a local level and tests the uniformity assumptions of the HPM.

7.1.2 Recapitulation of Stage 1 major findings and the response to research questions and hypotheses

The HPM used in Stage 1 is specified with a set of theoretically justified variables that offer strong predictive capability. The estimates produced by this model indicate the significance of accessibility factors on residential property prices. The results show that properties with high rail accessibility and also those closer to the CBD, nearby leading schools, at larger employment centres or waterside all experienced higher prices than otherwise equivalent properties found in areas without these attributes. On the other hand, properties nearby a rail corridor or adjacent to a main road both experience relatively lower property prices compared with other places.

The aim of Stage 1 hedonic price modelling is to determine if rail transit accessibility in Sydney influences property prices. Two forms of accessibility are considered in this research. The first, and primary focus of Stage 1 research, concerns residential locations in relation to rail access points. Proximity to rail access is measured by concentric zones mentioned above, which enables estimation of property value effects based on logical discrete distances. The second investigates factors that are convenience related. For the purpose of this research, the availability of station parking and the number of lines serviced by rail stations are considered qualitative factors that influence customer experience in relation to ease of access and traveller connectivity.

After controlling for the size of local commercial precincts and other factors, the coefficients for the variables representing the first to the fourth zone reflect the property premiums associated with different degrees of physical access to rail transit. The results indicate positive coefficients for each of these zones and substantial premiums at 13.1%, 17.1%, 13.1% and 5.5%, respectively. This shows that, when compared to areas of low rail accessibility, proximity premiums are highest in the second nearest zone ($77,463), dropping away in the third zone ($59,343) and again falling in the fourth zone ($24,915). The fact that the price premium in the first zone is less than the second is not unusual as the literature often reports that negative externalities nearby stations may have this effect.

Estimations relating to the quality of service show the provision of state transit parking at locations within the study area[37] leads, on average, to higher property values ($7,248) compared with locations without parking. Also, houses at locations that service a larger number of rail lines attract higher property premiums than locations that service less lines (each additional line adds $7,248 to the value of a residential unit). The results confirm expectations in relation to the impact of rail lines and clarify the previously unknown impact of commuter parking.

These findings provide a solution to the first research question posed in Section 1.4.2 of this study. The question reads: *Do RTSCs exhibit residential property proximity premiums and to what extent are they rail transit induced?* From a global perspective, the first part of this question is answered in the affirmative. The second part invokes the results outlined in Table 5.1 where the standardized beta coefficients clearly show substantial impact attributed to rail accessibility, particularly in zones two and three. However, the estimates derived from the HPM are essentially average estimates across the metropolitan area. Somewhat more granularity is required to resolve Section 1.4.2 sub-questions, which delve into aspects of the first question's initial, general enquiry.

Sub-question *1a* asks: *What do the observations reveal about local spatial variability, particularly as it relates to rail induced residential property premiums?* To consider this question, the study employs a relatively new local modelling technique known as GWR. Analysis involves an examination of the coefficient for the continuous distance variable, which substitutes for the discrete zone variables initially used in the HPM. The fact that the former estimate changes in magnitude and sign over space means that the concept of residential price decay and station distance does not uniformly apply across the Sydney metropolitan area. It also means the concentric circles around the station do not always display a positive coefficient. Indeed, in some cases property values may rise with greater distance to the station.

[37] Estimates are based on the combined observations of both high and low access zones.

Further evidence of rail transit impact of on property prices emerges in response to sub-question *1b*, which asks: *What accessibility factors are most influential in determining property values at RTSCs and how do these compare with the effects of other structural and neighbourhood characteristics?* The standardized beta coefficients generated by the HPM helps to determine which factors have the greatest impact on the dependent variable when units of measure differ. In this research, standardized beta coefficients are only available from HPMs and therefore estimates are expressed as averages across the metropolitan region. In terms of absolute values, these standardized coefficients show the greatest change in property value relates to distance from the CBD. In this case, an increase of one standard deviation of the CBD variable leads to a property price fall of -0.452 standard deviations. Of the remaining accessibility factors, zones two and three have the next greatest impact with a change of 0.191 and 0.155 standard deviations, respectively. Other than factors related to accessibility the greatest impact on property prices, in terms of a standardized measure, is the number of bedrooms (0.295 SDs), followed by the proportion of high-income earners in a neighbourhood (0.293 SDs), the number of bathrooms (0.157 SDs), the level of crime measured by the rates of assaults (0.121 SDs) and building age (-0.112 SDs). It should be noted that, apart from distance to rail, GWR also detects some local variability in distance to the CBD, number of bedrooms and bathrooms, building age and crime, but is not the case for the number of bathrooms and the concentration of high-income earners.

The impact of the local commercial complex at RTSCs on property prices is another important aspect of the present research. The findings show that the size of the local economic hubs has a bearing on residential property prices. Specifically, the results indicate the proxy variable is both positive and significant and show, on average, for each additional 10,000 people employed locally residential property prices increase by $6,297. This answers question *1c,* which asks: *How do premiums of property prices differ amongst locations targeted for different strategic economic roles?* Despite evidence of some local variability revealed by GWR both logic and evidence support the inclusion of a variable representing locations with different strategic roles in specifying models that determine the property price effect of rail transit.

Stage 1 hypotheses

Two testable hypotheses emerge from the general questions posed in relation to Stage 1 research. The first null hypothesis states:

> H_{1a}: *In relation to the Sydney metropolitan area, there is no significant difference in average residential property prices due to rail station proximity.*

In this study, global modelling results support the notion that rail stations cause property price premiums, moderated by the degree of accessibility. On the other hand, local modelling highlights instances where this rule does not apply. This creates a reporting dilemma. A principle aim of this research is to improve the methodological rigour. Accordingly, our hypothesis test is calibrated to include local variations and reveal exceptions. However, it is important not to base the validity of a hypothesis on the exception rather than the general rule. Therefore, our conclusion is best expressed as follows - As a general principle, we reject the hypothesis with the caveat that the alternative hypothesis is unlikely to apply in exceptional circumstances where rail access competes with the possibility of waterside living as the area's dominant attribute.

The second hypothesis states:

> *H_{1b}: Larger commercial complexes surrounding rail stations do not lead to higher local property values.*

Again, the global results show property prices respond positively to the size of a commercial complex, but local analysis shows this rule is influenced by the availability of waterside residential access and, as such, does not universally apply. Given that the focal point of this variable has ostensibly the same geographic reference as the point of rail access, the assessment of the first and second hypotheses is largely identical. Therefore, the second hypothesis is rejected with the same caveat applied to the first.

7.1.3 Research comparisons

There are very few overseas studies with which to make meaningful comparisons. Indeed, while there are many rail related property premium studies, they almost entirely examine the effect of new rail stations on property values rather than the effect of long-standing rail stations. Debrezion et al's (2011) study of the Netherlands is one of the very few recent studies that attempts to assess the value that residents place on rail accessibility at existing (established) stations.

Although Debrezion et al's study is limited in its assessment of rail effects on property prices to 'global' (averages) [38], there are some interesting comparisons that can be made. Using the HPM, the authors find a significant negative correlation between (increasing) distance from the station and property prices in two of the three major urban centres in the Netherlands[39]. Based on log

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[38] There is no spatial analysis. Also, see matters relating to multicollinearity (Section 2.1.6.2).

[39] Amsterdam and Enschede are both significant at the 1% level while Rotterdam is not significant at any level.

transformed data, regional differences in Netherlands indicate a range of correlation coefficients, for the most frequently chosen station, from -0.025 to 0.000[40], between Enschede and Rotterdam respectively. In the present study, this is equivalent to a regional range of -0.105 to -0.033, between the CSCWS and WSW regions, respectively. This suggests the premium paid for rail accessibility is substantially higher in Sydney than at the major urban centres of Netherlands. It demonstrates the relative importance placed on the Sydney urban rail system, compared with the Netherland experience.

7.1.4 Policy implications

The results of this study demonstrate the substantial effect of rail infrastructure on residential property prices. This clearly demonstrates that publicly funded transit improvements can increase the value of land and property. A community treated with rail infrastructure can also benefit from other indirect changes such as increased neighbourhood economic activity, the provision of public services and investment opportunities facilitated by sympathetic planning and land use regulations. It is perhaps the result of the city's polycentric design and accentuated by limited options in the form of road travel, that have made access to rail travel such a valuable commodity in Sydney and one that fortuitously benefits the residents of newly treated communities. In order to retrieve some of the financial benefits derived from public rail investments, the NSW State government is in a strong position to implement policies based on the concept of value capture.

Value capture focuses on realizing as revenue, by introducing fees, taxes or in-kind services, a portion of increased land value as a result of public investments in infrastructure (Ingram & Hong 2011). International attention to value capture as a source of public revenue has grown considerably in recently times. Interest in the concept is promoted by the current economic environment in which governments experience a combination of declining revenue from traditional sources, rapid growth in urban population and the on-going need for large investments in public infrastructure (Ingram & Hong 2011).

A number of value capture techniques have proven to be 'efficient, equitable and feasible options' for recouping the costs of railway projects from private land owners who otherwise receive "windfalls" under the beneficiary principle (Murakami 2011). These techniques include the establishment of special assessment districts, development right sales, property impact fees and land readjustment projects. Sydney's first limited value capture agreement was only recently

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[40] The first coefficient is significant at 1% and the second is not significant at any level

announced by the NSW Minister for Transport (Transport for NSW 2018). Under this arrangement the NSW Government will receive $355 million from the Macquarie Group for the air rights above a new metro station at Martin Place in the city centre. Similar development rights may apply to other commercial locations along the new North West Metro route.

The NSW government is also currently investigating broader use of value capture to finance the new Metro West due to be completed in the second half of the next decade. The government is evaluating the idea of placing levies on properties adjacent to stations to pay for the project. This is expected to provide a modest contribution to the capital cost of new rail construction, somewhere between 10 and 15% (O'Sullivan 2017). However, Stage 1 estimations from the present research clearly show that the perceived benefits of rail accessibility are capitalized in property prices well beyond the immediate vicinity of a rail station. Indeed, overseas experience shows substantially greater financial returns are feasible.

Private railway companies in Tokyo and Hong Kong have historically made considerable profits with little government financial assistance (Murakami 2011). For example, since the early twentieth century, the Greater Tokyo railway network was owned, built and operated by several, private and quasi-private transit companies. In total, there are seven major private railway companies (Tokyu, Tobu, Keikyu, Seibu, Keisei, Keio and Odakyu) that serve metropolitan Tokyo and each have operated successfully on non-fare revenues (Murakami 2011). In particular, Tokyu has a long history of self-financing new rail developments.

Tokyu's development process involves the practice of 'land readjustment' under which landholders release approximately half of their original parcels (commonly agricultural) in return for full access to infrastructure services including railway stations, roads, electricity and water. The land acquired through this method is used for road infrastructure, parks and other public spaces and the remainder is sold to cover costs of railway development. Specifically, railway construction costs are financed by commercial and Development Bank loans and the proceeds from land sales are used to pay off the loans. In this case, gains in property values due to rail treatment generate the company's profits. Tokyu's development approach is considered the most successful rail transit value capture scheme implemented in the late twentieth century (Cervero 1998).

Hong Kong's urban and suburban railway lines are owned, built and operated by Mass Transit Railway (MTR). This is a quasi-private transit company, which also operates the Kowloon-Canton Railway (KCR) (Dimitriou & Cook 1998). During the 1980s and 90s MTR received no financial support from the Hong Kong government to build railway infrastructure (Black 1985; Runnacles 1990; Strandberg 1989). Rather than funding, the authorities granted MTR exclusive development rights in areas surrounding projected MTR stations (Cervero & Murakami 2008; Hong & Lam 1998). This approach eliminated the need for open market land purchases, enabling relatively low transaction costs, increasing business incentives and enhancing the prospect of further rail and property development (Hong & Lam 1998; Tang et al. 2004).

Other international examples of value capture are found in the United States (Misczynski 2011), China (Anderson 2011), Britain and France (Booth 2011). Various forms of property taxes and fees linked to value capture are listed in Appendix D. Of these only annual property taxes are prevalent in Australia and these are generally applied at the municipal level. In order to meet government rail transit objectives, it is likely authorities will need to embrace the idea of greater funding from value capture, with a far broader geographical reach than is currently the case.

A policy of new rail infrastructure development financed through value capture can hasten the provision of key benefits for the Sydney region. Overseas experience shows these benefits include enabling planners to guide urban forms. For example, revenues from value capture can be used for development of transit-oriented communities, which often achieve high ridership levels and act to keep fares low (Murakami 2011). Value capture may also be used to support the growth of knowledge-based urban business clusters, sustained satellite job centres and service worker communities in suburban areas (Murakami 2011). Another advantage promoting economic growth is the downstream benefit of urban regeneration and, as previously mentioned in this study, the consequential improvement in labour productivity.

7.1.5 *Results from the perspective of various other interested groups*

Apart from policymakers, the findings of this research will interest property investors, developers, town planners and researchers. For property investors, it reveals the circumstances that lead to capital appreciation resulting from new rail infrastructure. It also helps developers to estimate consumers' willingness to pay for accessibility and other property attributes to enable optimisation of product offerings.

For town planners, the study provides greater understanding of the value attributed to new rail infrastructure in different locational contexts. For example, there is a noticeable difference in the willingness of households to pay for nearby rail access in the eastern compared to the western metropolitan sectors. The research also reveals that the perceived value of access to rail travel tends to dominate the value given to close motorway access.

From a research perspective, an important point to emerge from the study is the large contribution to property prices (and therefore premiums) generated by rail transit. This has been a matter of conjecture for many researchers regarding its implications for residential sorting. High proximity premiums are often seen as a precursor to displacement, gentrification and lifestyle changes that accompany transformations attributed to the introduction of rail services (Kahn 2007; Voith 1991). While current spatial strategies generally encourage value-added business interactions and generate even greater land premiums around the rail hubs, researchers have little understanding of the unintended long-term consequences of such strategies, especially in relation to demographic patterns. Evidence of rail induced demographic anomalies and the consequences for stakeholders, is addressed in Stage 2 research.

7.2 Stage 2: residential sorting and proximity to rail access

The purpose of Stage 2 is to examine the relationship between nearby access to rail and neighbourhood demographic characteristics including income, employment, educational attainment, life-cycle, origin and motor vehicle ownership. Initial research, conducted in Stage 1, reveals that rail access can lead to substantial property premiums in neighbourhoods nearby rail stations, which may affect affordability and therefore the ability of some households to access rail treated locations. In addition, other geographical changes are likely to occur in treated neighbourhoods, including densification, which produces high density residential housing types suitable for some, but not all, prospective inmovers. Specifically, Stage 2 research examines how these issues manifest themselves in different demographic profiles at neighbourhoods with high, compared to low, rail access locations. In terms of demographic profile, the long-established rail locations in this study are assumed in equilibrium reflecting the contemporary values of residents, their life-style/cycle preferences and financial circumstances.

Similar to Stage 1 analysis, this aspect of the study considers rail accessibility primarily as a matter of geographic proximity. Concentric rings surrounding a rail station define four zones with various degrees of functional rail accessibility. The fifth zone, beyond 2,000 meters from the rail station, is essentially the same suburban locality, but with low rail access. The latter acts as a control location in the analytical process. Two supplementary factors relating to rail accessibility (*PARKING* and *LINES*) are also included in this study along with various geographical predictors that complete the analytical function.

The data are aggregated at the SA1 neighbourhood level, which is the smallest geographical unit for release of ABS census data. Only those SA1s aligned with observations in Stage 1 analysis are included in the study. That is, the appropriate SA1 neighbourhood data are assigned to each house transaction observation, with the latter representing a point of distance to the nearest rail station. This leads to a total of 1,107 SA1 observations used in the research. The results of this study are then presented as distributions of residents according to the various socio-demographic characteristics outlined above.

7.2.1 Response to research questions and hypotheses

The overarching question assigned to Stage 2 research is: *Does the demographic profile of residents in high rail access neighbourhoods differ from that in neighbourhoods with low rail access and, if so, is this rail related?* In order to respond to this question, it is necessary to consider some important initial propositions. In this case, preliminary analysis focuses on the geographical characteristics of the high rail access neighbourhoods together with rail consumption patterns. The first estimations test the presumption that neighbourhood property premiums associated with rail access correspond with significant uptake of rail transit services. Second, the correlation between the prevalence of population characteristics and train usage is assessed to determine if there is evidence of rail travel preference amongst various demographic groups. The third explores the relationship between population density and residential building types and explains how this might influence residential sorting at neighbourhoods with high rail accessibility. These investigations are followed by an assessment of the degree to which the concentration of demographic characteristics corresponds with proximity to rail transit. The results of this four-part analytical approach are designed to explain the spatial dependency of demographic characteristics and, in particular, how they relate to the proximity of rail access. The following discussion considers these observations in relation to the Stage 2 research questions and hypotheses outlined in Chapter 1. Occasional reference to the analytical procedures used in the study is also included to elucidate some of the more abstruse concepts that define the relationship between demographic sorting and rail access.

7.2.1.1 Proximity premiums and the demand for rail transit

The first matter, mentioned above, is raised in response to sub-question *RQ2a*, which asks: *Is there a relationship between property price premiums and the demand for rail transit?* In order to answer this question, an OLS regression model is constructed to gauge the extent of demand for rail services in relation to rail station proximity and other accessibility features. The findings (Section 6.2) clearly show the spatial dependency of rail transit uptake. Importantly, the analysis reveals relatively stronger demand for rail services in areas closest to the station and less frequent usage with greater distance from the point of rail access. Rail transit uptake is also more likely in the Central, South and North metropolitan districts where commercial centres are more plentiful and better connected. In addition, the research shows that the more lines serviced by rail stations the greater the rail travel consumption. On the other hand, the analysis suggests the degree of consumer utility associated with rail transit is adversely affected by increased distance from the station and strongly influenced by district locality. This corresponds with the behaviour of the property price premium effect identified in Stage 1 research and gives weight to the assumption that rail users help underpin price premiums in the accessibility zones.

7.2.1.2 The relationship between train usage and the prevalence of various demographic groups

The second matter considers the relationship between the proportion of train users and the prevalence of various demographic groups in the study areas. Pollack, Bluestone and Billingham (2010) suggest there is a symbiotic relationship between certain demographic groups and successful transit. These authors note the importance of rail transit uptake and the accessibility for those who are likely to benefit most from rail transit. This aspect of research is designed to reveal these relationships.

Question *RQ2b*, relating to this section, asks: *Does a higher level of rail usage correspond with higher concentrations of specific demographic groups and, if so, which groups demonstrate this relationship?* A bivariate correlation test for correlation estimates reveals that different demographic groups respond differently to rail transit uptake (Section 6.3). The estimations reveal a weak positive correlation between the proportion of train travellers and the concentration of high-income earners and stronger, more significant relationship with university-qualified, professionals, unemployed and renters. Negative correlations with train travel register for the remainder of the demographic variables. The latter estimates reveal a weak relationship with the concentration of younger residents, but a relatively strong association with overseas born, families without dependants and motor vehicle ownership. The conclusion formed from this analysis is that rail transit take-up, at least in the case of some demographic groups, is influenced by factors other than the utility provided by rail transit and property price premiums.

7.2.1.3 The role of population density and housing type in determining residential sorting at subject locations

The above findings lead to the third matter that concerns patterns of population density and housing types and how these may influence residential sorting nearby rail stations. Research question *RQ2c* asks *What role might population density and housing type play in determining residential sorting at locations nearby rail access sites?* Section 6.4 reveals a strong relationship between population density and the geographical concentration of apartments. It also provides a useful insight into the demographic patterns that one might expect at rail-accessible locations. An assessment of residential tenure, primarily deduced from ABS reports, leads to the presumption that households in high density residential areas, and therefore those nearby rail stations, are predominantly younger, comprise few occupants, are generally poorer, primarily renters, largely overseas born and have lower car ownership compared to less dense areas, including those farther from rail stations. How well these presumptions meet RSTC circumstances is considered in the final research question.

7.2.1.4 The relationship between rail access and nearby demographic patterns

The final matter represents the primary focus of Stage 2 research. Question *RQ2d* asks: *What influence does rail access have on local demographic patterns?* The task here is to explain the differences in the concentration of demographic groups at neighbourhoods with nearby rail access, compared to other neighbourhoods. Specifically, the investigation seeks to understand if the pattern of settlement amongst various demographic groups responds to externalities associated with the provision of rail infrastructure. The analysis considers factors indirectly associated with provision of rail services, such as population density and changes in residential property type, which may influence residential sorting. In addition, the research is cognizant of the role that size of the local commercial district can play in determining settlement patterns.

The analysis designed to resolve *RQ2d* is similar to the procedures used in Stage 1. It is clear from the latter that the concentric zones surrounding rail stations offer accessibility benefits which diminish with distance from the rail access point. However, there are also substantial property premiums associated with closer access to rail. The decision to locate nearby a rail station is, to a large extent, determined by the cost benefit of settling in these areas. After controlling for other pertinent factors, this means neighbourhoods nearby stations are likely to be populated by households for whom the benefits of utility, derived from rail access, outweigh the location premiums. Therefore, similar to the pattern of rail induced property premiums deduced in Stage 1 research, the analysis for Stage 2 is designed to reveal rail induced demographic patterns.

The analytical procedure examines demographic group concentration by zones, which is similar to the concept of clustering by property premium. Indeed, property premiums are implicit in the concentric zones, which means the zonal analysis captures the relationship between the perceived value of rail access and residential sorting. While the zonal analysis offers considerable information about the nature of residential sorting in response to the availability of rail transit, the difficulty is determining the basis upon which the latter is seen to predict the former.

Section 6.6.1 introduces important criteria used to establish whether the externalities associated with rail transit influence residential sorting. This approach gauges how well the concentration of the focus demographic groups (or their opposites) aligns with the perceived value attributed to rail access as determined in Stage 1 research. The criteria require that the behaviour of the measure relating to the concentration of a particular demographic group is similar to the measure of property premiums over space. Essentially, the concentration of a group must rise between zone four and two (or conversely, fall between zone two and four) and the sign of the coefficient between zone one and three must be the same. Stage 1 research indicates that the zone four property price effect is small due to its remoteness from a rail station and therefore some dispensation applies to this zone in terms of the sign requirement. This exemption may give rise to a technical anomaly that inadvertently suggests a positive (or negative) relationship with regard to distance from the station, without an appropriate dominant (or minority) concentration in the combined high accessibility zones. This is addressed with a precondition by way of an initial criterion that requires a dominant demographic group form a proportionately larger (or smaller) concentration in the high accessibility zones (zones one to four inclusive) compared to the low accessibility zone five. For the purpose of this study, if both criteria are met then rail induced residential sorting is considered likely to have occurred.

The analytical exercise employs OLS regression to test the sign, significance and magnitude of coefficients representing the demographic factors. Controlling for population density, the size of the surrounding commercial district and the proximity to waterside, the results are evaluated in terms of the criteria. The outcome of this exercise provides the solution to a series of testable hypothesis relating to residential sorting.

Stage 2 hypotheses

The hypotheses relating to Stage 2 research are considered in four categories. Each hypothesis relates to rail accessibility in terms of distance to a station and not the qualitative factors associated with rail stations. A detailed explanation of findings can be found in Chapter 6.

Category 1: Income

The hypothesis concerning the relationship between rail access and the concentration of high-income residents states:

> *H_{2a}: The spatial distribution of residents, according to income, is associated with externalities relating to rail access.*

The estimated coefficient for the income variable reveals there is no significant difference between *GZ1234* and the base case *ZONE5*. These estimates show a *p*-value of .280, which means the data are consistent with the model from the null hypothesis. This suggests the combined high rail-accessible zone is unlikely to have an impact on sorting of households by income. These results are consistent with analysis conducted in Stage 1 reconfirming the independence of these variables, both of which appear on the right-hand side of the HPM equation.

Category 2: University Qualified, Professionals and Unemployed

The hypotheses concerning the relationship between rail access and the concentration of degree qualified, professional and unemployed residents state:

> *H_{2b}: The spatial distribution of residents, according to university qualifications, is associated with externalities relating to rail access.*
>
> *H_{2c}: The spatial distribution of residents described as professionals is associated with externalities relating to rail access.*
>
> *$H_{2d.}$ The spatial distribution of residents described as unemployed is associated with externalities relating to rail access.*

The analytical results in Section 6.6.2.2 show that both criteria are satisfied in the case of university-qualified and unemployed. This means we can accept hypotheses H_{2b} and H_{2d}, and H_{2c} is rejected.

Category 3: Average age, Australian born, families with dependants and renters

The hypotheses concerning the relationship between rail access and the distribution of residents by age, Australian born, families with dependants and renters state:

> *H_{2e}: The spatial distribution of residents, according to average age, is associated with externalities relating to rail access.*
>
> *H_{2f}: The spatial distribution of residents described as Australian born is associated with externalities relating to rail access.*
>
> *H_{2g}: The spatial distribution of residents described as families with dependants is associated with externalities relating to rail access.*

H_{2h}: The spatial distribution of residents described as renters is associated with externalities relating to rail access.

The investigation in Section 6.6.2.3 show that the variable *AVAGE* does not satisfy Part 1 criterion. However, both criteria are satisfied in the case of the remaining demographic characteristics. This means we can accept hypothesis H_{2f}, H_{2g} and H_{2h}, and H_{2e} is rejected. It should be noted that the negative coefficient signs for both Australian born and families with dependants reveal that overseas born and families without children are more likely to populate neighbourhoods nearby rail access rather than the focus groups specifically mentioned in H_{2f}, and H_{2g}.

Category 4: Motor vehicle ownership

The hypothesis concerning the relationship between rail access and the geographical pattern of motor vehicle ownership states:

H_{2i}: The spatial distribution of residents, according to average motor vehicle ownership, is associated with externalities relating to rail access.

A full assessment of the criteria for evaluating this hypothesis is provided in Section 6.6.2.4. The analytical results show that both criteria are satisfied in this case and have the appropriate common signs. This means hypothesis H_{2i} can be accepted.

7.2.2 Evidence of gentrification and displacement

The implications of the study findings for gentrification and dislocation of vulnerable demographic groups is of interest to urban researchers, residential action groups, town planners and developers. The purpose of this section is to consider the results in light of these interests. This section begins with an examination of comparable evidence from previous academic research and this followed by a discussion of the research findings implications from other stakeholder perspectives.

7.2.2.1 Comparisons with other academic research

The present research adds new methodology, context and scope to the existing small but emerging body of literature in this field. In terms of the former, it should be noted that Sydney offers limited counterfactual opportunity upon which to argue the existence or otherwise of rail related residential sorting effects. There is simply insufficient number and variety of locations, without rail access, to allow worthwhile comparisons. Nevertheless, the relative low density of Sydney rail stops[41]

[41] In comparison to many American and European cities of similar size.

provides the opportunity to compare demographic sorting at the same locations, when these locations are differentiated by high and low rail access. Hence, the context of this research is beneficial in terms of assessing the characteristics associated with gentrification and displacement. In this regard, all nine demographic variables, included in this study, are examined to ascertain evidence of sensitivity to the presence of rail transit.

The results of this research can be compared to the observations of Pollack, Bluestone and Billingham (2010). These authors hypothesize that the addition of rail transit may lead to gentrification, where this process is defined by a pattern of neighbourhood change marked by rising house costs and incomes. Their research indicates that, in these circumstances, rents tend to rise faster in rail-accessible neighbourhoods compared with other areas and owner-occupied units become more prevalent. The implication of Pollack, Bluestone and Billingham's study is that higher rents lead to displacement of vulnerable groups from rail-accessible areas.

The present study differs from Pollack, Bluestone and Billingham's in that it examines demographic patterns nearby mature stations that are assumed in equilibrium rather than transition. It is interesting, therefore, to consider the effect of station maturity and the implications for gentrification and displacement. The results of this research concur with Pollack, Bluestone and Billingham regarding price premiums associated with rail transit, but not in relation to higher incomes and home ownership. On the contrary, there is no evidence of a disproportionate number of high-income residents in neighbourhoods with high rail-accessibility (Section 2.2.6.1) and renting, as opposed to owner-occupation, is the prevalent form of tenure.

In regard to income, further analysis may help to illuminate the factors that determine the concentration of high-income residents. A supplementary exercise shown in Table E.1 Appendix E, explores the behaviour of high income concentration in relation to predictor variables for population density, the size of the local commercial district, distance to a recreational body of water and districts. Essentially, this approach involves the multivariate regression equation used in Section 6.6 but calibrated without non-significant zone variables.

Table E.1shows high income households are less inclined to live in densely populated SA1s[42]. Rather, they favour locations with larger commercial complexes surrounding rail stations; and tend

[42] This is consistent with a preference for settling in locations at the fringe of urban sub-centres.

to locate closer to a recreational body of water[43]. According to the standardized coefficients the metropolitan district variables have considerably more influence on the concentration of higher income households than other variables in the table. In particular, the district coefficients indicate the most desirable areas for higher income households are the Central and North metropolitan locations. Districts farther from the coast are less attractive for higher income households.

Overall, the results indicate there is no significant relationship between zones and high-income households. Therefore, the findings of this research do not support the descriptive analysis of McKenzie (2015), which suggests the top income bracket (equivalent to the variable used in this study) has a higher representation in rail-accessible neighbourhoods. However, the results of the present study add weight to Barton and Gibbons' (2017) argument that the role of transit (bus or subway) is secondary to larger processes that predict higher income. Overall, the results concur with presumptions in the literature that areas of superior socio-economic status predict concentrations of high-income households.

As mentioned earlier, there is no evidence of the suggestion by Pollack, Bluestone and Billingham (2010) that higher accommodation costs discourage renters from RTSCs. Indeed, the results show that renters have strong representation in high rail access zones and solidly rising with closer access to rail stations. A possible explanation is that many renters have greater flexibility and opportunity to access the benefits of rail transit. In general, renters are likely to benefit from higher levels of mobility compared with those who have family responsibilities. In contrast, the latter group, particularly those with dependants, are more likely attracted to out-lying areas, where accommodation space is cheaper and there is typically higher home ownership (Section 6.6.3.3). For many, not all, the rail-accessible zones are potentially transitional in the life-cycle process.

Similarly, the findings provide little evidence that overseas born are financially constrained from settling in RTSCs where there are considerable proximity price premiums. In the present study, the coefficient for population density, which is positively related to strata concentration (Section 6.4.3), is negative and significant.[44] This suggests that larger concentrations of Australian born are found in areas with lower population density and therefore the converse is true for immigrants. By implication, the results confirm Osborne's (2012) study, which posits that higher concentrations of ARPs leads to a higher concentrations of immigrants. Yet, even after controlling for population

[43] This is significant at the .10 level.

[44] A large coefficient is due to small observed values. *SA1PopDn* is measured in terms of sq. metres.

density, and therefore concentrations of ARPs, rail-accessible zones appear to be remarkably influential in determining immigrant settlement. Indeed, the findings from Section 6.6.2.3 indicate that, like renters, non-Australian born predominate in high rail-accessible zones. In fact, of all demographic factors studied in this research, both renters and non-Australian born claim the greatest magnitude of disproportionate representation at high rail access zones.

Gauging the effect of financial constraints is problematic. Many long-term settlers and newly arrived immigrants have significant financial resources. Others find themselves financially disadvantaged due to lack of access to financial institutions or family connections, which may inhibit prospects of home ownership. If overseas born settlers are in any way considered financially disadvantaged due to less access to financial institutions or family connections, their exclusion from rail-accessible zones is not evident in the results of this study (Section 2.2.6.1). Indeed, despite an expectation to the contrary, Pollack, Bluestone and Billingham (2010) also find no supportive evidence that more vulnerable ethnic groups are displaced by rail induced property premiums.

This research also provides little evidence to suggest that property price premiums nearby rail stations are associated with noticeable displacement of unemployed. The variable for unemployment passes the criteria set out in Section 6.6.2, which suggests rail travel provides an important service for this demographic group. This is intuitively correct given that alternative car travel has associated high operation costs (note also Table 6.3), which means there is less likelihood of car ownership in this case. The premiums associated with rail-accessible neighbourhoods need not be a major issue for this group. To some extent, this is mitigated by the provision of social housing in the Sydney metropolitan area and the tendency for this housing to be rail accessible.

This study also examines the effect of rail accessibility on age distribution. The findings indicate that the pattern of average age does not satisfy the criteria (Section 6.6.2) that establishes a relationship with rail accessibility. However, further investigation shows there is a strong correlation between average age and the coefficient for population density, where the latter also accounts for the frequency of strata unit occupancy. This confirms the analysis in Section 6.4.3, which shows there is a tendency for average age to fall with greater concentrations of strata housing. Indeed, there is some indication in this study that average age falls within the first three zones as one moves closer to the station. These circumstances paradoxically lead to the conclusion that a positive relationship between distance to the station and average age coincides with a lower average in combined zones one to four. The apparent anomaly is due to the positive sign of zone four. Furthermore, the magnitude of the reduction in average age between zone one and three is almost imperceptible. Further analysis reveals, overall, the behaviour of average age finds considerably more alignment in the variations of ARP concentration than in proximity to rail transit. [45]

These findings do not support the conclusions of McKenzie's (2015) descriptive analysis that shows younger age groups are more likely to reside in high rail-accessible neighbourhoods. Part 1 analysis, in this study, indicates there is no significant difference in the average age of residents in these areas compared with neighbourhoods with low rail accessibility. As mentioned, additional analysis shows that average age differences are more likely associated with population density and therefore residential property type rather than with factors directly associated with the availability of rail transit. To some extent, this may inadvertently explain the apparent link postulated by McKenzie's study that neighbourhoods with rail access often exhibit higher population density.

Demographic profile based on educational attainment is sometimes considered an indication of gentrification (Kahn 2007). In this case, a higher share of university graduates at a treated location is indicative of the phenomenon. McKenzie's (2015) descriptive statistical analysis shows that those with a bachelor's degree have a higher representation in rail-accessible neighbourhoods compared with other areas. The present study confirms McKenzie's findings and concurs with the assertion that residential sorting based on educational attainment is influenced by rail accessibility.

In regard to families with dependants, the results of this research support McKenzie's (2015) findings that households with children are more common in neighbourhoods without rail access. He estimates this is most likely the case for families with children between 6 and 17 and not families with children under 6 years old. McKenzie suggests residential location decisions of families with older children may be influenced by other neighbourhood characteristics such as school location and other suitable facilities. A particularly surprising finding of the present study is that there is no significant relationship between population density and the concentration of families with children. This suggests that families with older children, who are likely to need more accommodation space than families with older children, may be deterred from settling at these locations by the property premiums associated with nearby rail access.

[45] The results are not shown in Chapter 6

Finally, the results of this study address the assertion by Pollack, Bluestone and Billingham (2010) that the rail transit gives rise to higher motor vehicle ownership as a result of the potential for disproportionate concentration of high-income groups. In the present study, analysis of the relationship between motor vehicle ownership and rail accessibility use absolute numbers which, when translated to an order of magnitude, show a relatively large reduction in ownership with declining distance to a rail station. This raises the issue concerning which demographic groups are likely to vary their motor vehicle ownership as a result of living closer a rail station. To resolve this requires an understanding of the relationship between the concentration of various demographic groups and motor vehicle ownership.

While the behavioural traits of the demographic groups may have implications for motor vehicle ownership, testing their influence by inclusion in the multivariate regression analysis (see equation 6.5) leads to predictable multicollinearity. However, a bivariate correlation test provides useful insights into the relationship between variations in the concentration of these groups and motor vehicle ownership. A solution can be ascertained from the existing database, which provides a cross section of observations from both high and low rail access locations. Table E.2 in Appendix E shows the results of this correlation analysis. This analysis excludes variables that do not have a bearing on the demographic patterns of rail-accessible neighbourhoods. As a cautionary note, it should be emphasized that the relationships revealed are not subject to the effect of other neighbourhood characteristics such as ARP housing, which may moderate outcomes.

The table shows considerable variation in the strength of the relationship between demographic characteristics and motor vehicle ownership. Using Cohen’s (1988) analysis, the results indicate a strong correlation between motor vehicle ownership and Australian born, families with dependants, renters and the proportion of ARPs; a moderate relationship for university-qualified; and a weak relationship with the unemployed and average age. Each of the correlation coefficients is significant.

A strong negative relationship between university-qualified and motor vehicle ownership is unexpected. It suggests that university-qualified, which is associated with higher income, are less likely found in areas of high motor vehicle ownership. This belies the idea that the process of gentrification at rail transit locations creates an influx of residents with higher educational attainment and leads to greater motor vehicle ownership (Pollack, Bluestone & Billingham 2010). The present study also shows there is a positive correlation between university-qualified and rail-transit uptake (Section 6.3), which potentially obviates the group’s need for motor vehicle ownership. By association, the strong representation of university-qualified in rail-accessible areas makes sense of the lower motor vehicle ownership found in these areas. However, to suggest university-qualified have a lower propensity for motor vehicle ownership is problematic. Clarification of this situation requires greater understanding of the group's behavioural characteristics, which is beyond the scope of this study.

A weak, nevertheless, significant negative relationship between motor vehicle ownership and unemployed suggests that a higher concentration of unemployed is associated with areas of lower motor vehicle ownership. This supports the idea that the costs of motor vehicle ownership for this group may be prohibitive making public transport more attractive. It also suggests that unemployment is potentially a predictor for motor vehicle ownership. If this is so, a larger proportion of unemployment in areas of high rail accessibility logically reduces the demand for car ownership, compared to other areas. This is consistent with the findings.

Higher concentrations of Australian born correspond with higher levels of motor vehicle ownership. This suggests the relatively larger number of immigrants occupying areas nearby rail stations is likely associated with lower levels of motor vehicle ownership in these areas. It confirms the assumptions of analysis conducted earlier that shows many immigrants, either through habit or socio-economic constraints, exhibit lower demand for motor vehicles (Shafi, Delbosc & Rose 2017). If these assumptions are correct, then a causal relationship may exist whereby rail induced patterns of immigrant settlement lead to lower levels of motor vehicle ownership in areas of high rail-accessibility. Again, this is consistent with the findings.

Larger concentrations of families with dependants also correspond to higher levels of motor vehicle ownership. Families with dependants, who predominantly occupy neighbourhoods outside those with high rail-accessibility, have a greater need for motor vehicles to meet family obligations and offset the disadvantages of greater distance to rail, retail and other commercial services. This supports the notion that higher motor vehicle ownership is more likely in neighbourhoods with low, as opposed to high, rail access.

Renters have a particularly strong relationship with motor vehicle ownership. The negative sign of the coefficient in Table E.2 indicates that a higher proportion of renters in an area is likely to be associated with a lower level of motor vehicle ownership. The behaviour of renters is possibly related to other aspects of demographic profile. The ABS reports that areas with a high proportion of renters often attract transient groups, particularly young singles and couples (ID Consulting

2016) who may be less disposed to motor vehicle ownership. This is in keeping with results of earlier analysis regarding the prevalence of motor vehicle ownership and rail-accessible locations.

A matter alluded to earlier warns that a simple bivariate correlation test does not control for neighbourhood characteristics such as the local proportion of ARPs. The average level of motor vehicle ownership is generally lower where ARPs are more common. ARPs often have restrictions on the number of cars spaces available to residents, which means there are practical issues associated with car garaging in unit complexes. With a high proportion of unit complexes in rail-accessible locations one would expect residents in these areas have less opportunity to possess motor vehicles compared with areas where single dwelling houses are more common.

7.2.2.2 Community group perspective

From the perspective of community groups concerned with rail impact, the study reveals only mixed signs of gentrification and little sign of displacement. For mature rail stations in Sydney, post-treatment evidence of gentrification, often reported in the literature for relatively new station areas, is not obvious. Certainly, Stage 1 research shows a considerable price premium resulting from nearby rail access. However, Stage 2 analysis finds no significant evidence that residents nearby rail stations are wealthier, more likely to be professionally employed and predominantly homeowners, compared with those living in areas with low rail access. Only educational attainment provides any indication of residual gentrification at long established rail stations. As mentioned earlier, in terms of displacement, the present study shows no sign that potentially vulnerable groups such as overseas born or the unemployed, are marginalized due to housing price premiums nearby rail stations. Of all demographic factors examined in this study only families with children appear to have been adversely influenced by such premiums.

7.2.2.3 Residential planning perspective

Residential planning involves both government appointed and commercial developer interests. From these perspectives two important considerations emerge. First, the potential long-term investment return at RTSCs is considerable (Section 5.1.5). This research shows the value added to accommodation is highest 201 - 600 metres from station (zone two) and tends to fall with greater distance from the station. In addition, the research indicates that rail accessibility generates different proximity premiums depending on geographical location. In particular, the Western districts, with fewer employment centres and greater commuter distances, exhibit lower residential price premiums compared to the city’s Eastern districts. By controlling for neighbourhood characteristics, the analytical procedure employed in this study can be used to identify prospective residents' willingness to pay for nearby rail access and demonstrates how this varies across the metropolitan area.

Earlier discussion examined the concept of rail induced proximity premiums and how these may be captured by public authorities to facilitate new rail infrastructure development. This form of directed fund raising can be used to build local rail stations, develop pedestrian precincts at new RTSCs and also to compensate residents who may be adversely affected by new developments. In the absence of such appropriations, there is considerable profit incentive for commercial developers to generate new housing in newly created RTSCs. The study results show that neighbourhoods with nearby rail access are attractive to renters and overseas born who can be targeted by commercial developers. Locations, such as RTSCs, with high price premiums typically offer high rental rent returns, which are attractive to investors. Therefore, a high concentration of renters equates to high investor ownership. To attract investors, developers must maximize access to practical amenities but minimize the cost of potential future building maintenance. In regard to practical benefits, most compelling for potential investors is unimpeded access to transit and shopping facilities.

The second matter concerns the influence of rail accessibility on motor vehicle ownership. A definitive conclusion drawn from the present study is that motor vehicle ownership is significantly lower in neighbourhoods nearby rail stations compared with neighbourhoods farther away. This implies that greater accessibility to train stations tends to reduce car ownership, which supports one of the important principles associated with TODs. These centres generally form compact, pedestrian orientated communities featuring mixed land-use and easy access to rail transport. Many large cities internationally have embraced the concept of TODs as desirable, 'sustainable' communities where residents drive less and demand less for energy consumption compared to other areas.

Sydney authorities have so far shown little commitment to fully fledged TODs. Recent 'urban renewal' projects such as Green Square incorporate only some concepts associated with TODs. Despite the fact that there are a number of opportunities for TODs along the Northwest Metro rail corridor only inner-city sites at Victoria Cross, Martin Place and Pitt Street have been earmarked for this type of development, and in each case only on a limited scale involving airspace above the new rail stations. The challenge for planning authorities and developers is to fully grasp the opportunities presented by TODs and to consider whether these types of developments are appropriate for Sydney's future urban plan.

8 Conclusions

Understanding the long-term implications for communities treated with rail infrastructure, is of great concern for governments, equity advocates, business and academia, particularly in this age of burgeoning urban rail transit developments. This dissertation attempts to address the issue by establishing a framework in order to understand the spatial distribution of demographic characteristics and thereby explain settlement patterns at longstanding RTSCs. The analysis is conducted in two stages. The first involves an investigation of the utility offered by rail transit, which manifests itself in the form of variable property price premiums relative to the convenience of rail access. The existence of rail induced property premiums suggests a desire amongst some residents to access rail transit regularly and easily, but the corollary that follows suggests there are potentially other residents who are impeded, in this respect, by the cost of access. This forms the basis of the second stage of the research study, which seeks to estimate the effect of rail accessibility on residential sorting. After controlling for other pertinent factors, the analytical process employed in the second stage is designed to reveal the demographic structure and evidence of gentrification and displacement attributed to rail infrastructure.

8.1.1 Findings in relation to study objectives

The objective of the present research, set out in Chapter 1, is:

To determine the magnitude of rail induced residential property premiums across the Sydney metropolitan area and to reveal how, and to what extent, rail accessibility predicts the spatial distribution of demographic groups.

This research study meets the objective, which has two interrelated parts. The first part involves Stage 1 of the study, which investigates the existence of rail induced residential property premiums. Evidence from the analytical component of the study clearly identifies the magnitude of rail induced property premiums at locations with different strategic importance and in different regions across the Sydney metropolitan area. Overall, the results of this study provide strong evidence of rail induced property premiums. Indeed, the magnitude of the average effect in Sydney is particularly large relative to the findings of similar investigations undertaken in similar sized urban centres internationally. A possible explanation for this is that successive governments in NSW have been unable to match the Sydney's high population growth rate with the provision of sufficient road and rail infrastructure. Consequently, increasing road congestion in the city has accentuated the value placed on access to existing rail stations.

Addressing the second part of the objective involves adopting a procedure to assess the influence of rail transit access in relation to the concentration of several demographic factors. These factors include income, education, occupation, unemployment, age, locally born, families with dependants, type of tenure and motor vehicle ownership. Of the nine demographic characteristics considered there are three groups, income, professionals and age, found to be unaffected by rail accessibility. According to the criteria set out in Section 6.6.2, there is a case to suggest that the sorting of the remaining factors respond, in some way, to the externalities associated with rail access.

Despite the considerable property premiums associated with close access to rail transit, there is little evidence of prevailing gentrification or displacement, at least in terms of demographic sorting. Those demographic groups commonly linked to gentrification, including high-income and professionals, are not found to dominate areas of high rail accessibility. Only those with high educational qualifications are shown to increase concentration with closer access to rail transit. Similarly, there is no apparent evidence of displacement with respect to the groups that are generally considered to be financially constrained such as the unemployed and overseas born. Of those remaining demographic groups examined in this study only families with dependants appear to be sensitive to rail induced property premiums. This is evident after controlling for other factors such as population density, which influences housing types.

8.1.2 Matters for clarification

Further investigation to clarify various matters that arise from this study may enhance the value of current findings. For example, an important question remains whether the proportion of unemployed at RTSCs adequately meets demand. Analysis reveals that unemployment settlement is not disadvantaged by the property premiums. However, the low average unemployment rate overall and the very small incremental coefficient reflecting the change in high compared to low rail-accessible areas (see unemployment Part 1 analysis, Section 6.6.3.2) means that incremental numbers of unemployed nearby rail stations is infinitesimal. There is much more to learn about the nature and longevity of unemployment, but if affordable housing nearby rail stations is found to be inadequate then a financial solution for housing nearby new rail sites may be available through a special infrastructure contribution levy. In this instance, the provision of access to RTSCs for disadvantaged residents can be subsidized as part of a value capture program to mitigate the potential displacement effects of rail treatment.

As alluded to earlier, there is no evidence to suggest that overseas born are disadvantaged by the property premiums associated with rail transit. This group tends to dominate neighbourhoods close to rail stations. Even though proximity premiums are high, the analysis reveals that household location preferences for overseas born has more to do with ethnic tradition than means. If new immigrants are considered financially disadvantaged due to less access to financial institutions or family connections, their exclusion from rail-accessible zones is not evident in the results of this study (see Section 2.2.6.1). However, to fully comprehend residential location decisions of overseas born, there needs to be a greater understanding of immigrant profiles. This would enable examination of differences in sorting behaviour between long-term and recent new Australians. There is also the matter of ethnic status, which is not addressed in this study. To some extent, Australia's reputation as an egalitarian society obviates the need to explore racial differences regarding displacement. However, this concept should be confirmed.

Other matters that should be addressed concern age variation and families with dependants. For example, the study results show that age distribution across high and low rail access neighbourhoods does not vary. However, the study does not delineate the effect of various age brackets. Earlier discussion alludes to the possibility that both younger and older residents may prefer nearby rail access. This may obscure the existence of a middle age bias, detectable at a more detailed level of age analysis.

As previously indicated, families with dependants are not influenced by population density (and therefore residential type), but they show a preference for living on the fringes of nodal centres. This means families with dependants avoid the sizeable price premiums of neighbourhoods nearby rail stations and tend to reside in locations where motor vehicle ownership is higher. However, the magnitude of difference between the concentration of this group in high and low rail access zones is relatively small compared to some other factors that are influenced by rail access. It may be that, similar to the possibility of obscured age group patterns, different sized families may mask some of the more intricate effects of family residential sorting.

8.1.3 Future research

While resolving the matters outlined above will enhance the value of this research it will not alter the conclusions drawn from the study. Indeed, the analytical procedure outlined in this study provides considerable opportunities for future research due to its potential predictive qualities. Using information extrapolated from this research it is feasible to calculate the long-term sorting effect of newly treated neighbourhoods.

Researchers undertaking predictive analytics in this field should be cognizant of several matters that need to be addressed. First, there should be an understanding of the pace and timeframe of demographic transformation at newly treated neighbourhoods. Given that demographic patterns are largely the product of local neighbourhood characteristics it is important to understand the acceleratory effects of rail transit on these characteristics, particularly as it relates to factors such as the size of the local commercial complex and population density. Second, there should be an understanding of how the perceived value of access to rail transit changes over time. The modelling used in this study is calibrated with predictor variable coefficients based on contemporary values, which includes the current level of zone premiums. This may, or may not, be suitable to predict long-term residential sorting at newly created RTSCs. Changing trends in the impact of rail infrastructure can be assessed by studies that analyse data at different points in time. This leads to the suggestion that future researchers in this field of study, investigating rail induced property premiums, may consider using longitudinal data. This would better enable inferences in relation to causality, which is particularly relevant in Stage 1 research and elaborating a case for value capture. Third, there may be differences in the effects of the new Metro services compared to heavy rail investment which should be considered. Finally, future research should consider economic and government policy scenarios that may influence rail induced property premiums as well as the pace and direction of demographic transformation.

This dissertation is significant in that it is the first attempt to analyse all key demographic variables in a comprehensive exploration of RTSCs. Previous studies in this area have provided only limited explanations of residential sorting in response to public rail infrastructure investment, focusing predominately on short term gentrification. In this study, we advance a series of hypotheses concerning the contemporary effect of long-standing rail infrastructure. We also suggest a carefully constructed, rigorous framework to evaluate these hypotheses. However, this study is but an early stage in modelling rail induced residential sorting. It is progress toward addressing one of the foremost questions currently facing urban economics researchers.

Appendix A: Sydney Metropolitan Strategic Centres Detailed Criteria

<table>
<tr><th>Centre Type</th><th>Criteria</th></tr>
<tr><td>Global Sydney</td><td>Criteria

Within the Sydney Metropolitan Area there is one Global Sydney – it consists of central Sydney and North Sydney.
Primary focus for national and international business, professional services, specialised health and education precincts, shopping and tourism.
Cultural, recreation and entertainment destination of national and international significance with iconic public spaces and a focus for arts and cultural organisations and venues.
Dominant employment, economic and social role with a metropolitan, State, national and international catchment.
Global hub of the Australian economy.
High concentration of knowledge-based jobs with high skills levels, higher education requirements, high levels of management responsibility and attractive salaries.
Strong links with the international gateways of Sydney Airport and Port Botany.
Employs at least 400,000 people with capacity for more than 50,000 high and medium density homes.
Demonstrated capacity within commercial core to ensure adequate capacity for the expansion of office, business and retail space.
Demonstrated capacity within mixed use zoning around a commercial core to support core economic functions and provide for higher density residential uses.
Has good quality streetscapes and a range of activities at street level to service the needs of office workers and visitors, as well as the specialised retail needs of Sydneysiders from across the city.

Transport criteria

Transport catchment: metropolitan, State-wide, national and international.
Focal point and primary destination (for commuters and multiple other trip types) for high volume, high frequency public transport feeders (rail and bus) linked with the entire metropolitan catchment.
Express rail links with the Regional Cities and Global Economic Corridor.
Focal point in the motorway network with links to key gateways, Global Economic Corridor and Regional Cities.
Highest standard of freight access as a focal point in the Sydney freight network.

Description
Global Sydney consists of central Sydney and North Sydney. Central Sydney consists of Sydney CBD, Pyrmont-Ultimo, Sydney Education & Health, City East and Central to Everleigh. These precincts have distinct roles and identities – as detailed in the subregions section.
The governing bodies are the NSW Government, City of Sydney Council and North Sydney Council. The NSW Government has an ongoing commitment to the success of Global Sydney as the primary focus for business and linkages to the global economy.</td></tr>
<tr><td>Regional City</td><td>Criteria

Location of a Regional City relative to Global Sydney and other Regional Cities is such that opportunities for growth and success in meeting identified priorities (listed in the subregions section) are not limited by its employment and services catchment substantially overlapping with those of Global Sydney or other Regional Cities – and
</td></tr>
</table>

<table>
<tr><th>Centre Type</th><th>Criteria</th></tr>
<tr><td></td><td>for this reason, Regional Cities are typically located at least 20 kilometres from Global Sydney, and at least 15 kilometres from each other.
• Currently is, and/or has the potential to, operate as the capital of their subregion, providing a full range of business, government, health, retail, cultural, entertainment and recreational activities with good access to parklands.
• City planning reflects their significance as employment destinations with core commercial areas to support employment growth.
• Typically have extended development areas (such as Specialised Precincts) close to their city centres, which provide employment, services and residential opportunities that create stimulus for future development.
• Located in large and rapidly growing catchment areas.
• Suitably sized catchment area to sustain services and employment-generating land uses.
• Typically employ at least 15,000 people with the potential for growth beyond 30,000 jobs.
• Typically have capacity for 35,000 to 50,000 dwellings.
• Natural setting (such as a river) which enhances the city's amenity.
• Demonstrated capacity within a commercial core to ensure adequate capacity for growth and change in office and retail space.
• Demonstrated capacity within a mixed use zoning around the commercial core to accommodate a range of support services and activities, and residential development.
Transport criteria
• Focal point for regional public transport services (rail and bus) for commuters and multiple other trip types.
• Express rail links with Global Sydney.
• Linked with the motorway network to Global Sydney and links with key gateways, Global Economic Corridor and other Regional Cities.
• Focal point of regional arterial road network.
• High standard of freight access as a key node in the Sydney freight network.
Description
Regional Cities currently have, and/or have the potential to, operate as the capital of their subregion, with a full range of business, government, health, retail, cultural, entertainment and recreational activities. They play a critical role in maintaining and improving Sydney's quality of life because of their location relative to other concentrations of employment and services. The NSW Government has a strong interest in the success of Regional Cities as key structuring elements for Sydney.</td></tr>
<tr><td>Major centre</td><td>Criteria
• Key structuring elements for growth in their subregions. They represent significant employment destinations as well as being active mixed- use centres with higher density residential development.
• Act as the major shopping, business and service centres for their surrounding area, usually with a full scale shopping mall, council offices, taller office and residential buildings, central community facilities, a civic square, cinemas, sporting facilities and significant parklands.
• In many cases, are the focus for major institutions, principally serving immediate subregional residential populations on the public transport network.</td></tr>
</table>

Centre Type	Criteria
	• Have a minimum of 8,000 jobs, with the potential for more than 12,000 jobs. Planned major centres have the capacity to achieve 8,000 jobs within the timeframe of the Metropolitan Strategy. • Typically have capacity for around 9,000 to 28,000 dwellings. • Should retain a commercial core where this has demonstrated benefits. Mixed uses should be located around a commercial core and in some centres this may be a significant proportion of the centre. Residential development in the mixed use area can form an important element in revitalising the centre and provide for more housing choice. • Are divided into established, planned and potential major centres. **Transport criteria** • Transport catchment: subregional. • Linked to the metropolitan rail network directly or very high volume trunk bus services. • Focal point as a destination and origin for subregional public transport services (typically bus). • Focal point of subregional arterial and collector road network. • Freight access links with Sydney freight network. **Description** Major centres are the main shopping and business centres for their subregions. They also include residential development and other land uses within approximately a one-kilometre radius of the centre. The NSW Government has a strategic interest in the success of major centres as key structuring elements for Sydney and as focal points for subregional services. Note: Most major centres in Sydney contain large retail complexes which from time to time will require upgrading. This cycle of upgrading presents opportunities to achieve better design outcomes for the retail complexes and for surrounding areas and streets.
Town centre	**Criteria** • Typically comprise more than 50 commercial premises and services, generally with supermarkets, sometimes with a shopping mall/s and a variety of specialist shops, restaurants, schools, community facilities such as a local library and medical centres. • Tend to be a residential location, rather than an employment destination. Contain medium and high density housing and typically have capacity for around 9,500 dwellings. • Serviced by heavy rail and/or strategic bus and local bus networks. Some have ferry services. • Ideal elements are a town square, a main street, sports facilities and reasonable access to parkland. **Description** A Town centre is a large group of commercial premises (being retail premises, business premises and office premises) with a mix of uses and good links with the surrounding neighbourhood. It provides the focus for a large residential population.
Village Centre	**Criteria** • Typically comprise commercial premises and services for daily shopping and services. • Typically have capacity for around 5,500 dwellings and contain medium density housing. • Serviced by strategic bus and local bus networks as a minimum.

Centre Type	Criteria
	Description A Village Centre is a group of commercial premises (being retail premises, office premise and business premises) for daily shopping and services with a mix of uses and good links with the surrounding neighbourhood.
Neighbourhood Centre	**Criteria** • Typically comprise a small number of commercial premises and services. • Typically have capacity for around 500 dwellings, including some medium density housing such as townhouses and villas. • Serviced by local and/or strategic bus networks. **Description** A Neighbourhood Centre is a small group of commercial premises (being retail premises, office premises and business premises) typically focussed on a bus stop.

Table A.1 Sydney's metropolitan strategic and other centre classifications
(NSW Department of Planning and Infrastructure 2013)

Appendix B: High-Income Concentration - Comparison of Sydney Regions

Relating to Section 5.4: The table below shows a comparison of predictive variables for South West/Western districts (SWW region) and Central/North/Central West/South districts (CNCWS region).

Variable	SWW		CNCWS	
	β	*t*	β	*t*
(Constant)	14.285	255.209	15.894	507.718
BED	0.119	18.849	0.191	40.900
BATH	0.074	10.019	0.139	26.891
CAR	0.039	7.449	0.023	9.666
VILTH	0.059	5.835	0.027	3.580
LUX	-	-	0.064	4.537
FLFLOOR	-	-	0.810	10.922
LEV2	0.071	4.651	0.074	10.119
LEV3	-	-	0.169	13.153
LEV4	-	-	0.249	15.089
LOT	0.000	2.068	0.000	-5.880
BLDGAGE2	0.000	-27.528	-2.597E-07	-0.071
ln*(STN)*	-0.033	- 5.063	-0.105	-30.446
LINES	0.016	0.465	0.001	0.489
MW1	0.027	1.100	0.232	10.365
MW2	-0.033	- 2.299	0.079	6.512
MW3	-0.043	- 4.385	0.058	9.021
WTRSIDE	0.173	8.431	0.246	19.042
SCHZONE	0.048	3.416	0.029	8.498
Pc2KPLUS	0.017	7.074	0.033	72.790
ADJPARK	-	-	-0.105	-3.218
LESS100	-0.030	- 3.227	-0.098	-17.403
MAINRD	-0.013	- 0.891	-0.031	-4.752
MAJREG	0.063	5.459	-0.035	-7.078
R^2	0.671		0.691	
Adjusted R^2	0.668		0.690	
F-value	252.772		937.724	

Table B.1 HPM with ln*(ADJP)* as the dependent variable - a comparison of metropolitan regions

Appendix C: Standardized Coefficients - Australian Born, Families with Dependants and Renters

Section 6.6.3.3 discusses the standardized coefficients beta (Sβ) relating to demographic characteristics. The modelling technique used for Robust Standard Errors (RSE) does not provide an estimation of Sβ. Rather, an alternative estimation using SPSS and a non-RSE data set, which allows for Sβ, is shown below:

	PcAUSB			*PcFAMDEP*			*PcRENTER*		
	β	Sβ	*t*	β	Sβ	*t*	β	Sβ	*t*
(Constant)	-32.21	-	-18.57	42.03	-	34.25	46.23		21.92
ZONE1	-25.63	-0.38	-60.95	-9.18	-0.27	-30.83	24.32	0.45	47.54
ZONE2	-20.66	-0.46	-64.18	-7.67	-0.34	-33.66	21.06	0.58	53.77
ZONE3	-14.97	-0.35	-48.66	-7.56	-0.36	-34.71	18.94	0.56	50.60
ZONE4	-7.45	-0.16	-23.97	-3.71	-0.16	-16.84	10.79	0.28	28.54
PARKING	14.43	0.37	57.25	-4.28	-0.22	-23.97	3.24	0.10	10.56
LINES	1.15	0.09	13.04	-1.54	-0.23	-24.66	0.07	0.01	0.61
ln*(MW)*	10.72	0.36	57.09	-2.78	-0.19	-20.95	-3.13	-0.13	-13.73
SA1POPDN	-311.49	-0.14	-27.66	36.74	0.03	4.61	306.94	0.17	22.41
SEMPLOY	0.00	0.00	0.56	0.00	-0.45	-47.43	0.00	0.34	33.82
ln*(RBW)*	-0.17	-0.01	-1.22	2.08	0.20	21.07	0.69	0.04	4.04
SOUTH	-9.54	-0.19	-26.05	7.41	0.29	28.59	-5.10	-0.13	-11.44
WESTCEN	-13.38	-0.30	-35.03	19.50	0.88	72.16	-4.51	-0.13	-9.71
WEST	12.80	0.19	25.26	0.17	0.01	0.47	5.26	0.10	8.54
SOUWEST	-4.17	-0.06	-9.22	9.89	0.30	30.89	4.20	0.08	7.63
NORTH	-3.72	-0.08	-10.05	9.86	0.40	37.67	-11.01	-0.28	-24.47
R^2		0.746			0.485			0.414	
Adjusted R^2		0.746			0.485			0.413	
F-value		2333.98			748.04			560.06	
Observations		11,895			11,895			11,895	

Table C.1 Coefficient estimations showing standardized beta coefficients (Sβ)

Appendix D: Value Capture Mechanisms

Walters (2011) provides a detailed discussion of value capture mechanisms. The author identifies a wide range of techniques employed over time to capture the unearned incremental land value that occurs due to public and/or community improvements. Approaches can be categorized into two groups: The first group comprises fees and taxes and the second, non-tax value capture tools. The former group can then be subdivided into two types: one-time assessments and annual property taxes. Most common forms of fees and taxes are summarized as follows:

	What is taxable?	**What is the basis for determining the tax or fee.**	**When is the tax or fee collected?**
Development fee	Market value of new private investment in development.	Cost of overseeing new development or mitigating impact of development on public infrastructure.	Once, when permission to proceed with development is granted.
Estate tax	Generally, all land and property included in estates above a define threshold of total value.	Value of land and property transferred as part of an inheritance.	Once following death of estate owner.
Capital gains tax	Sale of real property.	Value of real property sold minus original purchase price and any subsequent improvement costs.	Once, as part of income tax system.
Transfer tax and stamp tax	Transfer of registered land title or other land rights to another party.	Market value of real property transferred.	Once, when registered land title or rights are formally transferred.
Betterment tax	Increment in real property value due to public investment or approved change in land use.	Land and improvement value after change minus land and improvement before change.	Once, at time of investment or when permission to change land use is granted.
Land rent or lease	Right to occupy and use publicly owned land.	Varies widely.	Annually, but can be more frequent.
Annual property tax	Privately owned or controlled land and immovable improvements.	1) Market value of land and property. 2) Physical characteristics of land and property.	Due annually, payable either annually, monthly or quarterly.

Table D.1 Taxes and fees on land and improvements

(Walters 2011)

.

Appendix E: Supplementary Estimates

Income

Section 7.2.2.1 Estimation of location variables that influence *Pc2KPLUS*. (Note: Based on multivariate regression results calibrated without non-significant zone variables).

$$Pc2KPLUS = f(SA1POPDN, SEMPLOY, \ln(RBW), SOUTH, WESTCEN, WEST, SOUWEST, NORTH). \tag{E.1}$$

Estimations of coefficients are shown in table below:

	Unstandardized		Standardized		
	β	Std. Error	Beta	*t*	Sig.
(Constant)	10.367	1.170		8.858	.000
SA1POPDN	-120.427	15.283	-0.176	-7.880	.000
SEMPLOY	7.252E-5	0.000	0.147	5.749	.000
ln*(RBW)*	-0.259	0.138	-0.049	-1.871	.062
SOUTH	-3.257	0.362	-0.244	-9.009	.000
WESTCEN	-6.323	0.360	-0.593	-17.578	.000
WEST	-4.210	0.167	-0.253	-13.706	.000
SOUWEST	-6.370	0.425	-0.435	-15.003	.000
NORTH	2.884	0.390	0.216	7.395	.000
R^2	0.503		Adjusted R^2	0.500	
$F(8, 1{,}097)$	38.809		P-value (F)	.000	

Table E.1 Coefficients of location predictors with *Pc2KPLUS* as the dependent variable

Motor vehicle ownership

A bivariate correlation test shows the relationship between variations in average motor vehicle ownership and the concentration of various demographic groups.

Variable Correlation	Coefficient	
AVMVOWN /PcUNIQL	-0.437	***
AVMVOWN /PcUEMP	-0.252	***
AVMVOWN /PcAUSB	0.589	***
AVMVOWN /PcFAMDEP	0.539	***
AVMVOWN /PcRENTER	-0.711	***

Table E.2 Correlation coefficients for *AVMVOWN* and demographic variables

*** Significant at the 0.01 level.

References

ABS – see Australian Bureau of Statistics

GaWC - see Globalization and World Cities Research Network

NUC – see National Urban Coalition

RICS - see Royal Institution of Chartered Surveyor

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