The influence of location type on the rail accessibility–property price premium relationship

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Abstract

This study adopts the hedonic pricing model to examine empirically the impact of new rail transport connectivity on residential property premiums in different types of multifaceted urban subcentres. Using this approach, the aim of this study is to assess the context of location in the accessibility–property price premium relationship, which has been largely ignored in previous studies. The author will attempt to show the effect of public investment in rail on property values, while positive, is modified by the extent and variety of locational attributes, which has implications for value capture potential in polycentric urban environments.

Statement of candidate

I, Laurence Victor Carleton, certify that the work in this thesis entitled "The effect of rail infrastructure on residential property values in Sydney: The context of value capture potential" has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis.

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

Laurence Victor Carleton (Student ID: 43186793)
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Chapter 1: Introduction

A common dilemma facing governments world-wide concerns their ability to finance investment in transport infrastructure in order to meet increasing mobility requirements. The issue has been exacerbated in recent years as governments face the dual dilemma of declining traditional sources of revenue and rapid urban growth that requires large investments in a variety of public amenities. In this context, the concept of value capture has gained considerable attention with various tax based or betterment schemes explored as possible mechanisms to finance new transport infrastructure. However, despite increased interest in value capture as an equitable and efficient means of raising public funds for new rail investment, the implementation of policy is inhibited by concerns regarding its suitability as a uniform tax model. Indeed, research to date shows a lack of consistency regarding the impact of new rail infrastructure across studies, and even within studies at ostensibly similar locations. Motivated by a desire to better inform the value capture debate, this study investigates the factors that underlie the relationship between new rail infrastructure and increases in property value, and the issues that contribute to the variability of results found in prior research. In particular, the study aims to address a matter long neglected in the literature, concerning the influence of a location's surrounding amenities in moderating the impact of new rail investments. The present research suggests the perceived value placed on new rail services is positive, although its impact is inversely related to the social and economic importance of the centre that benefits from new rail investment. This implies current attempts to estimate value capture potential are complicated by an additional, hitherto unexplained factor underlying the relationship between new rail infrastructure and property values.

1.1 Property price determinants, *nodes* and *places*

Real estate is generally considered a composite good comprising several value-determining features, the sum of which constitutes the value of a property as a whole. These features can be divided into three main categories: structural attributes such as the number of bedrooms, bathrooms and car spaces; accessibility attributes, including the availability of rail and bus stations, and highway entrances; and neighbourhood attributes comprising socio-economic characteristics and location amenities, such as schools, shopping centres, hospitals, entertainment venues and employment zones (Bowes & Ihlanfeldt 2001; Fujita 1989). This relationship may be represented as follows:

$P = f(S, A, N)$

Where:

P = residential property price

S = property structural attributes–bedrooms, bathrooms car spaces etc.

A = accessibility attributes–distance to rail and bus facilities and highway entrances

N = neighbourhood attributes–socio-economic characteristics and location amenities

As an accessibility attribute a rail station may produce positive and/or negative externalities resulting in different proximity premiums within the station's sphere of influence. 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 transportation 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).

The net effect of the contradictory influences of rail *nodes* on their corresponding *place* is often analysed in the empirical literature, with little consistency in findings regarding the overall size of the impact. However, there is general concurrence with the view that areas immediately adjacent to rail stations are subject to either positive or negative influences, depending on the externalities emitted by the station. In addition, researchers generally agree that further from the *node*, positive influences on property prices tend to prevail, peaking at or before a comfortable walking distance to the station, and then gradually tapering to inconsequential levels at the full extent of the impact area (Bajic 1983; Damm et al. 1980; Dewees 1976; Voith 1991). This is illustrated in Figure 1.

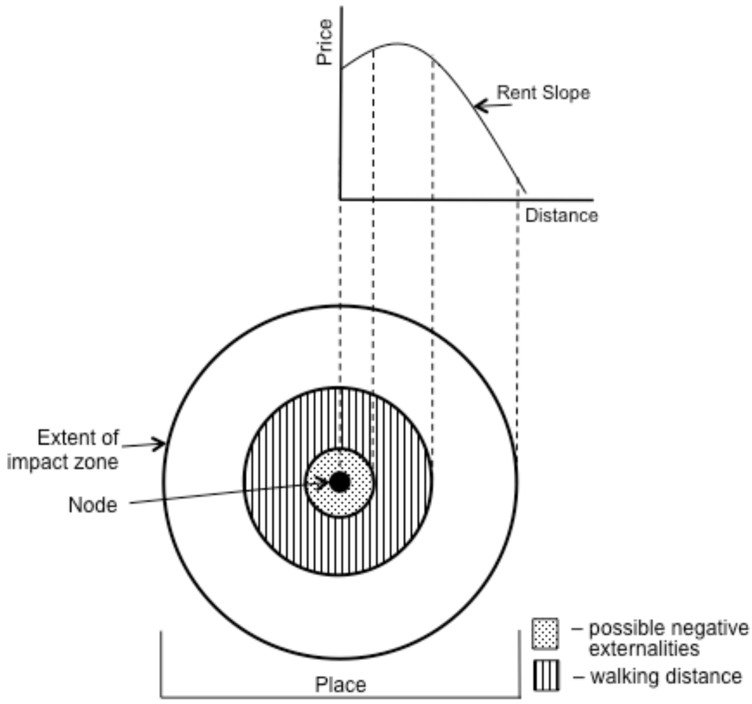

Figure 1: General effect of *node* on *place*

While the literature indicates there is general agreement that a rail station has an effect on its *place*, conjecture remains regarding the extent of its impact. The paucity of evidence to account for considerable variations in the observed impact of new rail services has also restricted researchers' ability to generalise the findings of empirical studies. This prompted a meta-study by Mohammad et al. (2013), who used regression analysis to identify factors believed to have a bearing on results and to investigate the relative importance of these in contributing to observed variances. The results show significant variations in the impact of rail investments due to a number of factors including, international context, type of land use, type and extent of rail service, distance to station, accessibility to main roads and methodological approach. However, Mohammad et al. (2013) also found that including location in the estimation model did not significantly change values. This specific finding is contested in the present study.

There are a number of good reasons to suggest that locational characteristics may be undervalued in Mohammad et al.'s (2013) meta-analysis. First, their study is restricted by its inability to clearly distinguish locational differences. For example, the analysis considers two proxies for testing locational effects: one comprising central business district (CBD) studies only and the other combined CBD and non-CBD studies. Clearly, it is beyond the capability of the model to provide an adequate estimate of locational influence given the data used.

Second, a number of studies show that location is a likely factor in determining the extent to which rail infrastructure affects property valuations. For example, a study of the Metropolitan Atlanta Rapid Transit rail system indicated both positive and negative impacts of rail on property values depending on location (Bowes & Ihlanfeldt 2001). Similarly, Du and Mulley (2007) in their study of the Tyne and Wear district found variations in results across different locations. Third, Mohammad et al.'s (2013) finding regarding the lack of location influence is counterintuitive. This is because rail stations as *places*, particularly in more diffused polycentric urban environments, vary in size and variety of public amenities such as employment opportunities and shopping, cultural and educational facilities, each having its own attraction which may reduce the need for intra-urban transport (Bayer, Ferreira & McMillan 2007; Black 1999; Des Rosiers et al. 1996; Oates 1969; Sirpal 1994). Therefore, it is feasible that residents located in urban subcentres with a sufficient critical mass of amenities to satisfy local community needs are likely to value public transport services differently from those residents without such benefits.

In this study, it was speculated that the more closely multi-faceted urban subcentres emulate the myriad activities of the city centre the less likely its residents require transport to access employment zones, shopping and other activities. Hence, the challenge presented here was to determine if, and if so to what extent, the impact of rail investments on property values differs between locations when the principal determinants of price variation identified by Mohammad et al. (2013) are taken into account. In the context of Bertolini and Spit's (2005) theoretical framework, this means investigating the influence a station's surrounding *place* has on the perceived value of rail accessibility. The task involves identification of different locations benefiting from similar rail service improvements and estimating the ensuing changes in property values. Ceteris paribus, this reveals whether location type moderates the influence on changing property values resulting from new rail improvements. The possibility that the value of new rail investment is perceived differently in different communities within the same metropolitan region gives rise to the potential for a variety of property value-added results. Hence, understanding the possible effects of spatial heterogeneity is fundamental for assessing potential value capture resulting from new rail investment.

1.2 Research question

In summary, empirical research shows that capitalisation of rail transport systems into property values varies significantly between studies, and that results are not easily generalisable. While some variances have been explained as contextual or methodological, there has been no serious consideration of how different communities value new rail infrastructure and the effect this has on property values. Hence, to determine if the potential for value capture exists and whether it varies in different locational contexts, this study needed to address the following research question:

Does public investment in rail infrastructure affect nearby property values and how is this influenced by the locational characteristics of the impact area?

1.3 Objectives

To answer the research question, it was necessary to address four main objectives. The first was to identify factors contributing to the rail infrastructure–property value relationship. The second was to define the study's analytical approach. The third was to examine empirically the relationship between new rail investment and property values, and the fourth was to identify the impact and explain differences attributed to location.

1.4 Approach and scope of the study

This study examined the effect on property values following the introduction of the new Epping to Chatswood rail link in Sydney. The study employed a similar methodological approach to that used by Grass (1992) who analysed the effects of a new metro railway in Washington, DC. In her study, Grass used the hedonic pricing model to compare property values in the impact areas with those of appropriate control locations, before and after construction of the rail line.

The primary focus of the present study concerns properties adjacent to rail stations at Epping and Chatswood, and their nominated control areas. These stations represent the 'bookends' of the rail link and both existed prior to construction of the new line. The impact of an augmented rail service at Epping, as a *town centre*, and Chatswood, as a *major centre*, were compared to determine the existence, or otherwise, of a relationship between urban subcentre types and size of rail investment impact. As a supplementary exercise, the study also examined the impact of two other circumstances generally recognised in the literature that influence value capture potential and which are pertinent to the research question. The first involves an examination of the relative effect of an entirely new station at Macquarie Park compared with the effect of augmented services at Epping and Chatswood. The second considers the relative distance to the station within the rail catchment area.

1.5 Organisation

This dissertation comprises six chapters. The following chapter provides a literature review of the theory and empirical findings concerning the impact of rail infrastructure on residential property values. In this chapter, the applicability and appropriateness of the hedonic pricing model is also discussed, together with the theoretical justification of the price attributes included in the model. Chapter 3 briefly outlines the broader issues relating to the subject region, the spatial organisation of economic activities, details of the specific locations that were studied, and pertinent information concerning Sydney's rail infrastructure and property market. Chapter 4 explains the methodology and data collection process used to prepare for the analytical phase of the study. This chapter also presents the study's hypotheses and reveals expectations. Chapter 5 contains the study's empirical results, together with analysis and discussion of findings in relation to the research question and hypotheses. Finally, Chapter 6 draws conclusions relating to the findings, identifies the value of the study, assesses its limitations, and offers recommendations for future research.

Chapter 2: Literature review

To test for evidence of property premiums derived from rail infrastructure, it is necessary to invoke the principles and estimation tools of land value theory dealing with market behaviour, in relation to space consumption and locational preference. The following literature review is arranged in three parts: The first is an account of land value theory development from its foundations in the observations of early theoreticians; the second contains a review of recent empirical literature that investigates the influence of various factors associated with rail infrastructure and their impact on nearby property values; the third provides a description and review of the proposed hedonic pricing model, which emerges as the preferred analytical tool to account for factors that affect property values.

2.1 Theoretical literature

Land value theory owes its foundations to the work of early nineteenth century political 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. The basic principles identified by Ricardo were later refined and developed by German agriculturalist and amateur economist von Thünen (1830) who conceptualised the relationship between land value and output in terms of concentric land use patterns. Von Thünen argued 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 further from the market where property cost is lower and transport distances greater. Von Thünen's theory thus introduced the seminal concept of a land value–market proximity relationship.

In the early twentieth century, land economist Hurd (1905) extended von Thünen's theory to the urban context. He 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 influenced by direct proximity to the city centre, the effect is mitigated by the emergence of transport infrastructure, which facilitates urban expansion by effectively reducing the remoteness of outlying urban locations. In this new urban paradigm, "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 1905, p. 146).

Haig (1926) confirmed the relationship between property value and location, and stressed the dominating influence of the city centre. He suggested the city's influence is due to its myriad activities and its centrality in relation to surrounding suburban locations. Close 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 described this relationship as the 'cost of friction'. He suggested 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.

Tiebout (1956) addressed the issue from the home seeker's perspective. He theorised that home seekers choose their location by selecting neighbourhoods offering bundles of public amenities that match their optimal mix of services, subject to their budget constraint. Hence, 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. This implies a 'buyer's premium' is capitalised in the value of properties near to locations offering desired amenities. It also suggests that certain neighbourhoods produce their own buyer's premium based on distance to particular local amenities, in addition to overall CBD proximity.

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. In his 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. Later, Muth's (1969) extensive empirical work added 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.

The concept of a cost associated with closer proximity to the city centre, with its dominant cluster of economic activity, remains an important tenet of land value theory. Equally important, theoretical literature highlights the influence of transport infrastructure in facilitating the development of urban subregions, which produce their own cluster of amenities and hence their own gravitational attraction. However, the ability to measure these phenomena eluded early researchers. While Alonso's (1964) model was built on practical observable elements and provided a valuable framework within which to view the problem, it proved onerous to implement as a tool of analysis. By the 1970s, the challenge for empirical researchers was to devise a simpler, more efficient tool to estimate the value of transport infrastructure and other public amenities nested in land value.

In the mid-1970s researchers began to estimate the relationship between property value and public amenities using regression techniques to account for the observable and unobservable determinants of house prices. This concept has its theoretical justification in the hedonic pricing model pioneered by Rosen (1974). The hedonic pricing model and its derivatives formed the basis for the vast majority of empirical studies in this area undertaken in subsequent decades.

2.2 Empirical studies

Property values vary due to differences in structural features, neighbourhood characteristics and accessibility attributes. Prominent among these is the concept of accessibility, the principles of which are explained by the Alonso–Muth bid-rent theory. This theory posits that consumers' willingness to pay for property is a decreasing function of distance, relative to the city centre. The 'demand friction' surrounding the city centre is moderated by access to rail transport, which facilitates the dispersion of urban population. As a consequence, a proportion of city property demand is transferred to suburban transport hubs, which generally develop their own price gradient relative to their transport centre. While the price gradient generated by transit accessibility is commonly identified in the literature, empirical evidence reveals considerable variability across studies (see Table 1). This section discusses factors that may account for these variations such as spatial heterogeneity, demographic characteristics, type of land use, type of rail investment, effect of technology and methodological considerations.

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 1: Sample of empirical study variations
Source: Mohammad et al. (2013) (augmented)

2.2.1 Spatial heterogeneity

Empirical studies show that the impact of rail infrastructure on property values may vary spatially due to the heterogeneity of research locations. 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*.

2.2.1.1 Geo-cultural differences

An important factor contributing to the variability of estimated property value due to rail investments is geo-cultural differences. For example, Mohammad et al. (2013) showed that research conducted in different continents can produce significant variations in the perceived value of transport accessibility. Studies generally indicate higher percentage changes in property values for cities in Europe and East Asia compared with those in North America. The authors suggested a possible explanation is the greater dependence on public transport in most of the European and East Asian continents, compared with the car-oriented culture that typifies North American cities. In addition, the literature indicates values increase at a greater rate in congested zones, compared to those with less traffic activity (Clower & Weinstein 2002).

2.2.1.2 Proximity to the CBD

The CBD is often a major focus of amenities and economic activity, which means 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 commuter rail access to the CBD incur proximity premiums compared with those in similar neighbourhoods without direct rail access. Voith (1993, p. 361) also suggested "the estimated value of CBD accessibility fluctuates with the economic health of the city", indicating the CBD economy is an important factor contributing to variations in property valuation due to rail infrastructure.

Empirical studies identify different results with regard to the relationship between CBD proximity and the impact of rail stations on nearby property prices. For example, 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 affect on price variations.

The type of urban layout can also influence 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 on the Los Angeles metropolitan area. Their findings show property values are heavily influenced by access to a number of urban subcentres. This means the existence of multiple locations offering accessibility to large employment precincts and other amenities such as shopping, educational and recreational facilities diminishes the value of CBD-focused transport. In their conclusion, 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 go on to 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).

2.2.1.3 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) confirmed 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. For example, studies by Winston and Langer (2006) indicate both private and commercial vehicle costs tend to decline in urban areas as rail network mileage expands.

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 at which point additional traffic encourages commuters to seek alternative means of transport. Hence, the availability of quality travel alternatives maintains the traffic congestion equilibrium and increases the overall volume of commuter traffic. This is supported by 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). Hence, given equivalent accessibility, the effect on property values is likely to be shared in proportion to the demand for each.

2.2.1.4 Distance to the rail station

Estimates of rail impact indicate the extent and magnitude of proximity premiums are generally relative to the distance from rail access points. 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 & Mclean 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 early study by Dewees (1976), examining 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 overall impact of new, or improved, rail connectivity on commercial and residential property values is generally considered to lie within a radius of approximately 1,000 metres (RICS 2002). Estimations of changes in property values within the impact area, due to new rail investment, are examined in the present study.

2.2.1.5 The effect of place

The perceived value of rail accessibility reflected in property prices is subject to the availability of local amenities that satisfy community needs. For example, Debrezion, Pels and Rietveld (2011) found that local large-scale employment zones exert their own gravitational effect, which presents a key variable explaining different locational proximity premiums. Similarly, local shopping facilities generate a proximity premium (Colwell, Gujral & Coley 1985; Sirpal 1994), as do local schools, which tend to vary in attraction, according to their reputation (Bayer, Ferreira & McMillan 2007; Black 1999; Brasington 1999; Gibbons & Machin 2006; Kane, Riegg & Staiger 2006; Oates 1969; Rosen, H & Fullerton 1977).

Collectively, the availability of employment opportunities and shopping, education, social, cultural and entertainment facilities generate a community proximity premium commensurate with the quality, size and variety of its aggregate amenities. This suggests the greater the influence of local attributes, the lower the utility gained from accessibility to rail transport. Hence, the value of rail access as an explanatory factor in determining proximity premiums potentially diminishes with an increase in the attraction of other local amenities. These concepts are tested in the present research.

2.2.2 Demographic characteristics

Property values, derived from proximate causal relationships with rail infrastructure, may also be influenced by a locality's demographic characteristics. For example, rail station proximity premiums are higher in lower-income residential neighbourhoods compared with those in higher-income neighbourhoods (Bowes & Ihlanfeldt 2001). This suggests that low-income residents rely more on public transport and therefore attach greater value living close to a train station. Gatzlaff and Smith (1993) also claim that the variation in the findings of their empirical research can be attributed to local demographic factors. However, Voith (1991) 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.

2.2.3 Type of land use

Another factor leading to variability in the impact of rail stations on nearby property values is the type of land use involved in the research study. For example, railway stations generally have a larger affect on residential properties than on commercial properties (Debrezion, Pels & Rietveld 2007). However, the impact on commercial property values tends to be greater than on residential properties within a short distance from stations (Cervero & Duncan 2002; Debrezion, Pels & Rietveld 2007; Weinstein & Clower 1999).

2.2.4 Type of rail investment

Research shows that different forms of rail service have different impacts on property values. For example, a number of studies indicate that commuter/metro rail stations produce a relatively greater impact on property values than light rail stations (Cervero & Duncan 2002; Debrezion, Pels & Rietveld 2007; 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.

The impact of rail infrastructure on property values may also differ depending on the level of service and its perceived benefit to local communities. 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) found 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) demonstrated property value changes of approximately 10%, 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. The proposition that the introduction of a new station provides greater benefit compared with efficiency innovations or augmented services at an existing station, is an important concept that has implications for this study in relation to the suitability of a uniform value capture tax. Property value changes resulting from the recent introduction of a new station are also a useful indication of the value a community currently places on rail transport.

2.2.5 The effect of technology

Some studies identify technology as a moderating influence on the perceived value of rail infrastructure. For example, Gatzlaff and Smith (1993, p. 66) found 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". The authors suggested this may be attributable to advances in telecommunications, computer network coverage and other areas of technology that tend to make companies 'footloose' in 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.

2.2.6 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 hedonic pricing model, geographically weighted regression, 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 noted 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 reasons for these anomalies are not specifically addressed by the authors although they suggest some instances of estimate variation due to methodology may result from limited sampling, which means more comprehensive future analysis will be required to confirm and explain their findings.

2.3 The hedonic pricing model

Early approaches to estimating the effects of transport infrastructure on property values used regression techniques to examine the observable determinants of house prices and factors relating to proximity. This method was refined by Rosen (1974), to become known as the hedonic pricing model which, along with its variations, is now the most widely used model for the purpose of estimating the impact of rail infrastructure on property values. This section examines aspects of the model in relation to its use in empirical research.

2.3.1 Model definition

Rosen's (1974) model imputes values of property features by estimating the relationship between property price and quantities of the property's various attributes. The model posits that property values derive from a particular mix of differentiated products, that can be specified by a vector of observable variables $x = [x_1, x_2, \ldots, x_n]$, from which consumers derive utility. Hence, the hedonic pricing model provides an estimation of a consumer's willingness to pay for each property attribute, subject to income constraints and moderated by the consumer's particular 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 hedonic pricing model is ordinary least squares (OLS) regression analysis. The model estimates the unobservable factor by the regression equation:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots\ldots + \beta_n X_{ni} + e_i$$

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 measureable substitutes. For example, proximity may be represented by a series of discreet distance intervals within which properties are located relative to a particular amenity. 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.

2.3.2 Advantages and limitations of the model

The main strength of the hedonic pricing model 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 hedonic pricing model makes a number of assumptions, relating to its definition, which may affect the validity and interpretability of its results. The limitations of the model generally relate to these assumptions and include equilibrium in the product market; access to perfect information with respect to the characteristics of the product; no transaction costs; and finally, that the dependent and independent variables are linearly related, regardless of priori justification.

While the assumptions of the hedonic pricing model are clearly unrealistic, recent advances in model definition, functional form and improvement in tests of rigor 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 2002, p. 116). The model is also used extensively by the Reserve Bank of Australia (RBA) and the US Federal Government (Moulton 2001).

2.3.3 Model specification and functional form

Coincidental with Rosen's work in defining the hedonic pricing model is Grether and Mieszkowski's (1974) account of the model's specification. The authors apply various techniques to overcome weaknesses resulting from the model's definition, and in doing so provide the first notable application to demonstrate 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 model includes property structural characteristics such as floor size, building age, number of bedrooms, bathrooms and car spaces, and various utility feature inclusions. In addition, their study considers neighbourhood characteristics, representing both positive and negative externalities that are likely to be capitalised in the cost of housing.

An issue concerning application of the hedonic pricing model is that structural, locational and neighbourhood characteristics are not always linearly defined. This means choosing an appropriate functional form is an important aspect of model specification. It requires examining the data to determine best fit, a process significantly assisted by a priori knowledge of the variables and their likely behaviour (Craig, Palmquist & Weiss 1998). A variety of transformations including semi-log and log-linear forms are available to the researcher, and suitable functional forms can be determined by availing to theory and econometric techniques (e.g. Box-Cox testing).

Another issue commonly considered by researchers in the process of model construction concerns examining the relationship between independent variables. The difficulty facing researchers is that the hedonic pricing model assumes the selection of appropriate variables that are mutually exclusive and the average effect of missing variables is insignificant. The hedonic pricing model is most efficient when defined with a limited number of highly explanatory variables. 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 hedonic pricing model becomes unwieldy and unstable with too many explanatory variables in the mix.

The inclusion of a large number of explanatory variables may also 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 hedonic pricing model.

2.3.4 Examples of model variables

Property values vary spatially due to their physical structure, accessibility attributes and neighbourhood characteristics (see Figure 2). Specifications of the hedonic pricing model, for residential housing, generally include an attribute vector of variables assigned to each group of characteristics. Common variables used in the literature and the procedures for measuring these variables are discussed in the following sections.

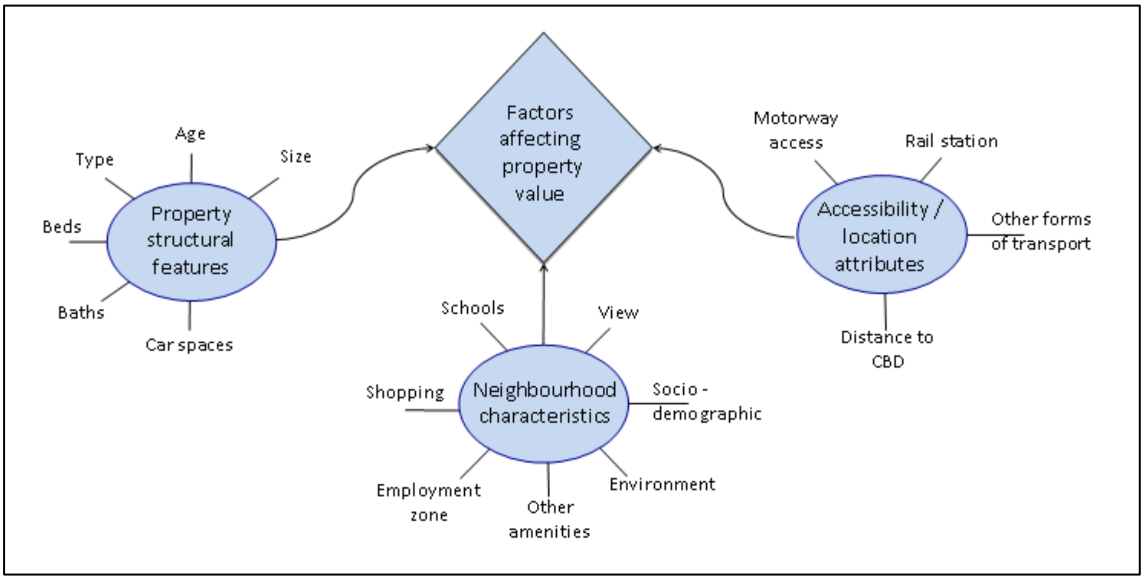

Figure 2: Factors affecting property values

2.3.4.1 *Structural attributes*

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

Studies also 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 as a result of their historical significance. In this regard, Clapp and Giaccotto (1998) suggest that two counterforces regarding the age coefficient exist: an obsolescence factor and a vintage effect that is subject to demand-side vicissitudes.

Finally, Chau, Ng and Hung (2001) noted that builder's goodwill may have an effect on the value of property. 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 is to incorporate this type of intangible attribute into a pricing model.

2.3.4.2 Accessibility attributes

A property's value is partially conceived in terms of its fixed locational attributes. These are unchangeable, immoveable features (Follain & Jimenez 1985; Orford 1988) such as rail stations, highway entrances and bus depots, which are usually quantified by an appropriate measure of accessibility. Other features of *place*, relating to locational attributes, are often considered under the heading of neighbourhood characteristics.

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 with close proximity to these amenities, because they provide access to the CBD. Therefore, the value of rail stations, can be calculated by estimating property values relative to distances from the nearest station (So, Tse & Ganesan 1997).

2.3.4.3 Neighbourhood attributes

Previous empirical studies indicate property price variations are significantly influenced by neighbourhood characteristics, which include both socio-economic and 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 schools (Clauretie & Neill 2000; Jud & Watts 1981), shopping complexes (Des Rosiers et al. 1996) 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 (Chattopadhyay 1999).

Socio-economic variables are generally proxied by scales representing a range of most desirable to least desirable neighbourhood characteristics. Crime has been measured by rates of robbery, aggravated assault, vehicle theft and arson as a proportion of 1,000 residents (Haurin & Brasington 1996). Other studies use the percentage of high school dropouts as a proxy for crime and vandalism (Li & Brown 1980).

Schools are a municipal service that may command higher proximity premiums and their impact is often measured in terms of performance levels or expenditure per student. Another facility is the local shopping complex, which is commonly measured by distance to the amenity (Des Rosiers et al. 1996; Sirpal 1994). In addition, a number of studies include employment zones as a location characteristic. Most factor CBD as the largest employment zone. However, others demonstrate the countervailing influence of urban subcentres in polycentric environments (Heikkila et al. 1989).

Views are often considered a residential amenity associated with a neighbourhood (Benson et al. 1998). Properties with good views generally command a premium, which is reflected in the floor level of residential apartments (So, Tse & Ganesan 1997). The significance of views makes it an important component of the hedonic pricing model construction. Numerous studies have shown that 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). Research also indicates this amenity is often not uniform and depends on the quality and type of view (Benson et al. 1998). In addition, there generally appears to be a strong correlation between floor level and premium paid due to a corresponding improvement in quality of view (So, Tse & Ganesan 1997).

Finally, 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 particular 'disturbance' level, buyers tend to react adversely to close airport proximity. 'Disturbance' levels may be gauged by the recorded decibels at noise-affected locations. Reduced air pollution is also seen as having a positive influence on property prices. Measures for air and water quality include the level of particulate matter and the concentration of bacteria, respectively (Chattopadhyay 1999).

2.4 Isolating the impact of rail accessibility

Perhaps the most ambitious study to isolate the impact of rail infrastructure was undertaken by Debrezion, Pels and Rietveld (2011). The authors' primary aim was to examine the relative influence of rail transport accessibility compared with all other location attributes. Using the hedonic pricing model their study involved more than 60,000 property sale transactions in the Netherlands. It also included a large number of physical house characteristics, socio-economic factors and individual accessibility variables such as distance to nearest rail station, most frequently used station, highway entrances/exits, railway lines, employment zones, schools and hospitals, as well as accounting for station service quality. A total of 82 explanatory variables were used in the model producing a high coefficient of determination. However, despite the inclusion of such a large number of variables, the authors were rewarded with little consistency in relation to expected outcomes.

The limitations of simultaneously investigating all possible proximity factors that affect house price premiums are clearly demonstrated in Debrezion, Pels and Rietveld's (2011) study. The problem with their model is its clear lack of parsimony in an attempt to capture every conceivable factor in determining property values. In addition, the issue is exacerbated by the inclusion of several spatially segmented markets (Andersson, Shyr & Lee 2012). The poor results of the study are also symptomatic of the difficulties researchers face 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 issue well recognised by Vessali (1996), who warned against placing unrealistic expectations on the model.

The problem of spatially correlated locational attributes can be resolved by an alternative approach used by Damm et al. (1980) and later refined by Grass (1992). This process involves using the hedonic pricing model to estimate the difference in property values following an event affecting rail services at an impact area, 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. The methods used by these authors were generally applied in this study.

Chapter 3: Background

This chapter provides a brief summary of information relating to the subject region for the present case study. It reveals the context in which observations are made and how communities are differentiated for the purpose of investigating the impact of new rail infrastructure at different location types. In particular, the chapter contains: a brief profile of the City of Sydney; an investigation of the city's metropolitan strategy; an overview of its rail network; details of the subject rail link project; and a description of the demographic and functional characteristics of the three locations (Epping, Chatswood and Macquarie Park) along the rail link that form the focus of this study.

3.1 Sydney and its metropolitan strategy

Sydney is designated an Alpha+ global city, second tier to London and New York (GaWC 2012), with 4,757,000 residents and a current growth rate of 1.7% (ABS 2013). Coping for more than 1,500 additional inhabitants each week presents a major challenge for the state government, in particular dealing with job creation, residential accommodation and sufficiency of transport infrastructure. With limited options for either centre city or greenfield expansion, policy-makers have opted for land use intensification resulting in the emergence of a polycentric urban environment. A signature feature of Sydney's development strategy is the Global Economic Corridor (GEC), which involves a series of interconnected urban subcentres and specialised employment zones designed to disperse job opportunities along with retail, health and cultural facilities (see Figure 3). In addition, zoning regulations have been implemented to encourage residential accommodation nearby public transport infrastructure at urban subcentres. Part of the GEC strategy was the provision of a rail link between Epping and Chatswood, which provides the focus of this research.

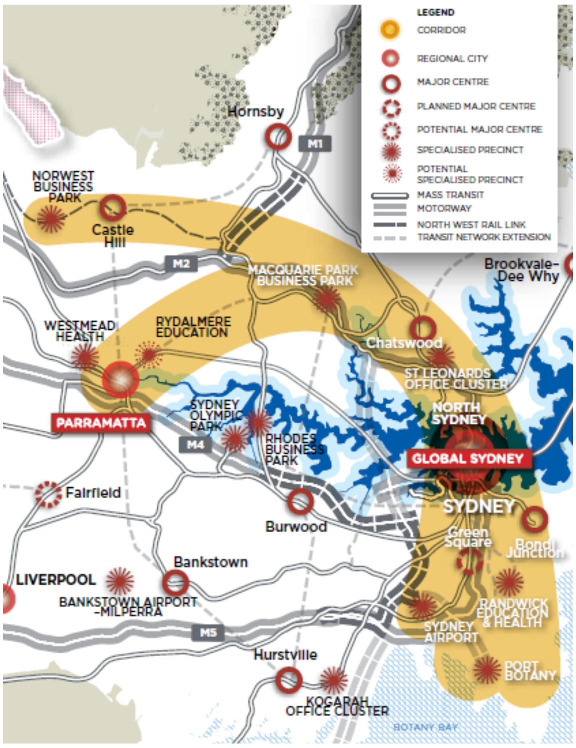

Figure 3: Global economic corridor
Source: (NSW Department of Planning and Infrastructure 2013)

3.2 Sydney rail network and the Epping-Chatswood rail link

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 core of the Sydney system reach high frequencies, use tunnelled right-of-way and grade separated tracks with interval services, which typifies metro systems. Shared tracks, combining intercity and freight operations on some routes in the city's middle to outer suburbs result in slower and lower frequency scheduled services, which are characteristic of commuter systems.

Sydney's metropolitan rail services have experienced consistent passenger growth (see Figure 4) averaging approximately 1.4% annually in the past decade, which is equivalent to Sydney's average population growth during the same period (ABS 2013). Chief competitor of the rail system is the automobile, which accounts for around 80% of commuter distance travelled (see Figure 5).

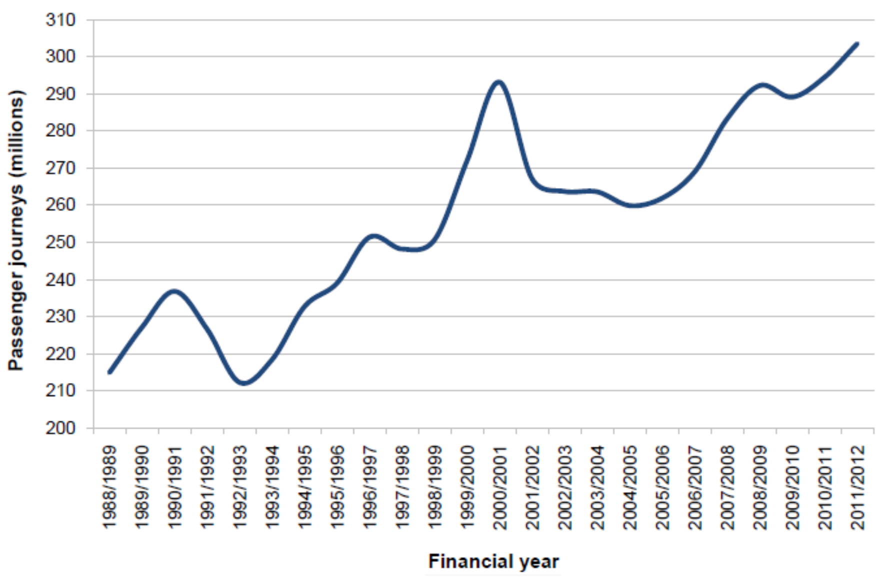

Figure 4: Annual CityRail passenger journeys since 1988–89
Source: (NSW Bureau of Transport Statistics 2012)

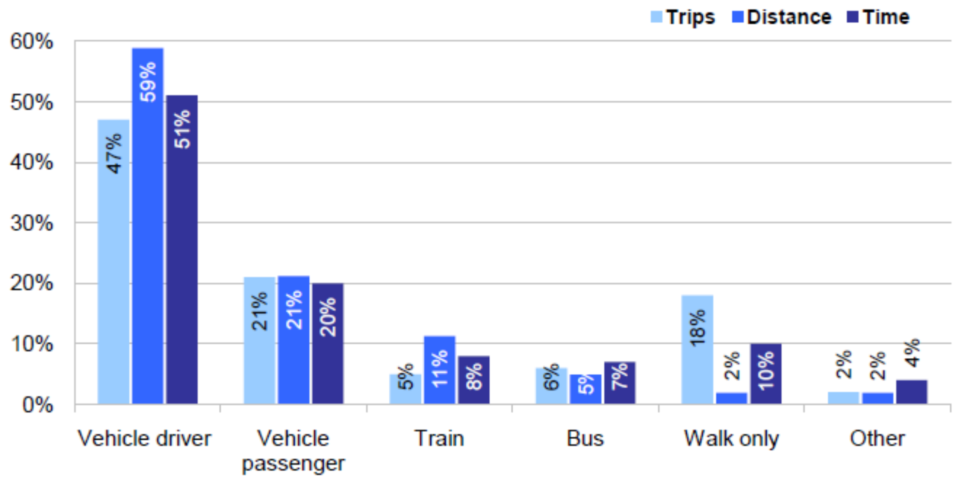

Figure 5: Mode share of trips by Sydney residents on an average weekday
Source: (NSW Bureau of Transport Statistics 2012)

The Epping-Chatswood rail link forms part of the rail infrastructure network servicing the GEC. Construction of the line began on 25 November 2002 and services commenced on 23 February 2009. The link forms part of the Northern Line, designated T1 Northern via Macquarie Park, providing rail travellers on both the east and west northern trunk lines cross access and accessibility to the Macquarie Park employment zone (see Figure 6). Patronage on the line has grown substantially since it opened (see Table 2). Morning peak station entry numbers indicate Epping station generates more outbound journeys for commuters than Chatswood, in both absolute and proportionate terms. Conversely, Chatswood has more absolute and proportionate inbound journeys than Epping, which is consistent with the functional importance of Chatswood as a major employment zone (see Figure 7). These passenger flows suggest that rail infrastructure is likely to be valued more highly in Epping than in Chatswood.

Figure 6: Epping-Chatswood rail link
Source: CityRail

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 2: Patronage by line
Source: (NSW Bureau of Transport Statistics 2012)

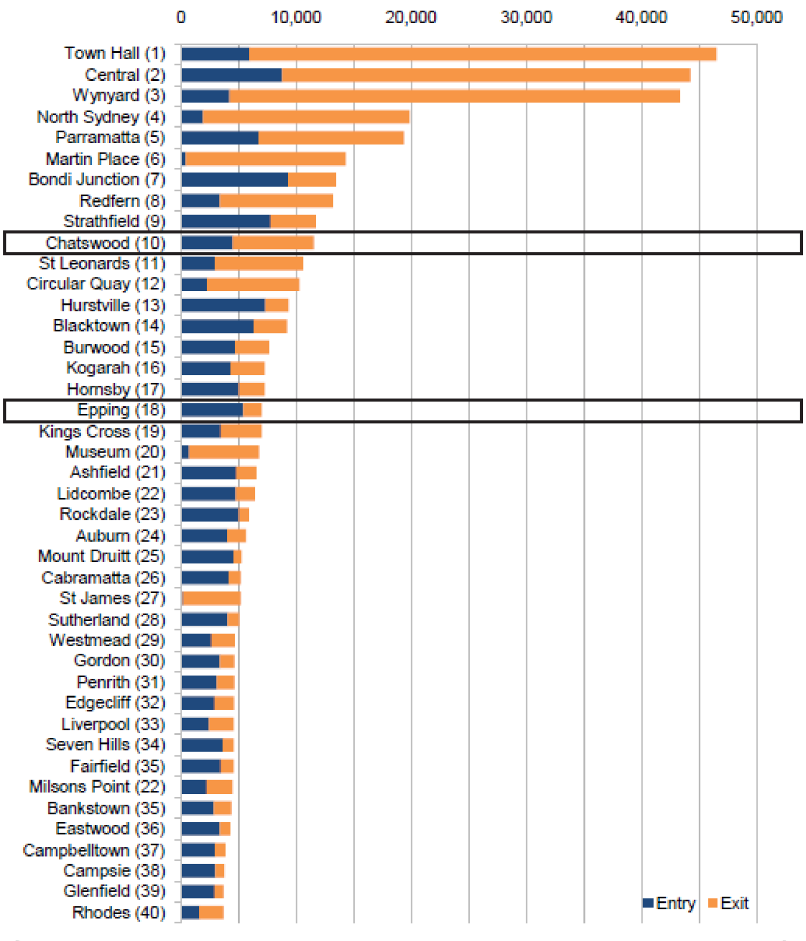

Figure 7: Top 40 busiest rail stations (am peak 3.5 hours)
Source: (NSW Bureau of Transport Statistics 2012)

3.3 Metropolitan centres policy and subcentre classification

Sydney's metropolitan strategic centres classifications provided by the Department of Planning and Infrastructure offers a suitable means to distinguish urban subcentres according to the size and variety of their location attributes. Classifications include, *global Sydney*, *regional cities, specialised centres, major centres, town centres, villages and neighbourhoods*. Brief descriptions of these are contained in Table 3 below, with full details 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 3: Sydney's metropolitan strategic centres classifications
Source: (NSW Department of Planning and Infrastructure 2013)

3.4 Functional profile of the subject locations

This section briefly summaries the functional characteristics of Epping, Chatswood and Macquarie Park. Section 3.5 reviews and compares the demographic profile of each.

3.4.1 Epping

According to the New South Wales (NSW) Department of Planning and Infrastructure, Epping is classified as a *town centre*. With limited local facilities the new rail link to Macquarie Park provided Epping residents with easier access to additional employment, education and retail facilities. Currently, Epping has a commercial/retail floor space of approximately 46,000m^2, with retail services comprising around 2,400m^2 (NSW Department of Planning and Infrastructure 2013).

3.4.2 Chatswood

Chatswood is classified as a *major centre* satisfying the criteria of significant economic importance, mixed functionality and comprehensively serviced by public transport. 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 tower development adjacent to Chatswood rail station. It 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).

3.4.3 Macquarie Park

Macquarie Park *specialised centre* is located at the current northern anchor point of the Global Economic Corridor and provides unique commercial space for high technology businesses in a campus-style working environment. The locality comprises Macquarie University, Macquarie University Research Park, Macquarie Retail Centre, Macquarie Commercial Park and Riverside Corporate Park, covering an area of 3km^2, providing approximately 800,000m^2 of commercial and retail floor space (NSW Department of Planning and Infrastructure 2013).

3.5 Socio-demographic profile

Spatial analysis reveals a variety of socio-demographic results for communities surrounding the three locations involved in this study (see Table 4). The primary interest of this study is a comparison of Epping and Chatswood. Both these locations support similar sized populations and have other shared characteristics including family numbers, average number of children per family, median age, full time employment, unemployment, median weekly income and proportion of professionals. However, there is a marked difference in car ownership, which is higher in Epping reflecting a greater need for accessibility to other centres. In addition, recent migrant arrivals and rented accommodation tends to be significantly higher in Chatswood, indicating a community with comparatively less long-term social cohesion. The latter differences are likely symptomatic of the locations' divergent economic, social and cultural significance.

	Epping	Chatswood	Macquarie Park
Population (persons)	20,227	21,194	6,143
No of families	5,643	5,568	1,187
Ave children per family	1.7	1.6	1.5
Median age	38	35	30
Attending university or tertiary institution	30.0%	26.7%	58.0%
Migrants - arrived 2001 – 2011	17.9%	27.0%	34.8%
Employment			
Full Time	61.6%	62.8%	62.2%
Part-Time	28.3%	26.1%	22.6%
Unemployed	6.1%	6.2%	10.8%
Away from Work	4.0%	4.9%	4.4%
Occupation – Professionals	39.7%	38.0%	40.4%
Median Weekly Household Income	$1,683	$1,616	$1,258
Transport to work by Train	21.8%	23.9%	11.2%
Couple families with children	54.7%	45.9%	32.3%
Occupied Private Dwellings:			
Flat, unit or apartment	27.9%	59.3%	77.7%
Rented	28.7%	41.9%	63.1%
No of Motor Vehicles			
None	9.5%	20.9%	24.7%
1	42.2%	48.6%	55.4%
2	34.9%	22.8%	15.9%
3+	11.7%	5.7%	1.8%
Distance to the CBD	19km	11km	18km

Table 4: Demographic profile
Source: (ABS 2011 census data)

Macquarie Park's demographic profile indicates a high concentration of migrant residents (having lived elsewhere in the decade prior to the 2011 census). This is consistent with the cultural diversity expected to surround a major university. Other sharp differences that distinguish Macquarie Park's demographic profile from the Epping and Chatswood communities are reflected in the area's higher university attendance rate, lower medium household income, higher proportion of rented accommodation and lower car ownership.

While the socio-economic profile of Macquarie Park diverges markedly from Epping and Chatswood it is the similarity of the latter locations that is most significant for this case study. Indeed the primary focus of the present study is to compare the response to new rail infrastructure at Epping and Chatswood in terms of property value uplift, and similarities in socio-demographic profile imply any different responses to rail investments are likely derived from the physical attributes of *place*. The following chapter defines the empirical strategy employed in this study to reveal how the role of *place* moderates the influence of new rail investment on property values.

Chapter 4: Empirical Strategy

This study is concerned with evaluating the effect of new rail infrastructure on property values and determining if this is moderated by the extent and variety of other public amenities within the impact zone. The Epping-Chatswood rail link provides an ideal case study that largely obviates all other known conditions that may lead to differences in the effect of rail investment (see Section 2.2). This enables a comparison of a *town centre* at Epping and a *major centre* at Chatswood where both received similar benefits as a result of augmented services at pre-existing rail stations. In a supplementary exercise, the assumption of equivalent benefit was relaxed to investigate the effect of a new station at Macquarie Park compared with the effect of augmented services at Epping and Chatswood. Finally, the study examines the influence of rail investment on property prices within the rail catchment area of each location. In this study, it is argued that each of these situations is likely to produce disparities in the impact of rail investment, which question the suitability of a uniform value capture tax.

The analytical process followed in this study was similar to that undertaken by Grass (1992) in her evaluation of a new metro rail line in Washington, DC. Grass's analytical approach involves both a rail investment impact area and a control location. The purpose of including an impact and control location is to demonstrate the magnitude of property price differences between communities that are fundamentally similar in terms of demographic profile and access to public amenities, apart from rail accessibility.

There are four essential differences between Grass's (1992) approach and that of the present study. First, this study investigated three rather than two phases of the rail project, to provide a more comprehensive understanding of rail investment effects at various stages of development (Yiu & Wong 2005). Second, Grass assumed equivalent base prices in the impact and control areas, whereas this study followed Bajic's (1983) approach and estimated the starting price differential as the basis for examining changes in the relationship between impact and control during each project phase. Third, this study offers greater granularity by including evidence of changes within the impact area. This supplementary research involved investigation of two zones within the impact area comprising a 530-metre (one-quarter of a mile) radial distance, representing an approximate walk-up zone (Dewees 1976), and a 531–1,000-metre radial distance representing the remainder of the likely rail impact area (RICS Policy Unit 2002). Finally, this study considered the moderating influence of the surrounding locational attributes, or *place*, as a factor determining property value changes in each impact zone. The following sections provide identification of the target area, the study hypotheses, a description of the model and its functional form, details of data collected, and a discussion of results that were expected from the analytical process.

4.1 Study target area

The target of this study is three locations along the Epping-Chatswood rail link: Epping, Chatswood and Macquarie Park. The first two locations received the benefit of a new rail link augmenting services at existing rail stations, and the latter received an entirely new rail station. The benefits accruing to both Epping and Chatswood are similar, which primarily involves new connectivity to Macquarie Park. In both cases, there is no additional benefit in regard to CBD access in either cost or commute time saving and there are no physical changes to Epping or Chatswood train stations that are likely to produce additional long-term negative externalities in the immediate vicinity of the station. Finally, there were no ‘shocks’ or events at either location during the research period that were likely to cause a departure from the general trend in Sydney property prices, apart from new rail investment.

The third location is Macquarie Park, which received three new stations as a result of the rail link. The focus in this area is the Macquarie University station, which offered local residents first-time rail access to the east and west trunk routes of the northern rail corridors and ultimately the CBD. In this study, the estimated property value effect due to a *new* station at Macquarie Park was compared with the effect of *augmented* rail services at Epping and Chatswood.

The selection of control locations was based on economic stability, similarity of demographic profile and close proximity to the impact area. This approach was taken to provide homogeneity in terms of neighbourhood characteristics. Carlingford was selected as the control location for Epping because it features a similar-sized shopping centre and comparable types of residential housing. The Carlingford control area is close to an existing rail station, which although not ideal, was unlikely to have any influence on the results of this study, because of its position in the rail network, its low patronage and stagnant passenger growth. Lane Cove was the allocated control for Chatswood. This suburb is immediately adjacent to Chatswood and has a similar demographic profile, access to high street shopping and an equivalent employment precinct. Finally, Top Ryde was the allocated control for

Macquarie Park. Top Ryde has similar characteristics to Macquarie Park with a large shopping mall, nearby employment zone and a TAFE educational facility.

4.2 Hypotheses

The challenge for this research study was to explain if, and if so to what extent, demand friction emerges at different locations receiving new rail infrastructure. Based on Haig (1926) and Alonso's (1964) theories, savings in transport costs and time made possible by new rail investment are likely to result in a greater willingness to pay for properties in the impact area, compared with other locations. Hence, the introduction of the new Epping-Chatswood rail link is likely to increase property values nearby rail stations along the route. This led to the first hypothesis:

H1: Property prices nearby rail stations increase if those stations benefit from new or improved accessibility due to new rail investment.

However, empirical evidence suggests the value of a rail station is influenced by the extent of its service (Debrezion, Pels & Rietveld 2007). That is, the more substantial the enhancement the greater the benefit and perceived value. In this study, three locations were examined: Epping and Chatswood, which received additional connectivity supplementing pre-existing services, and Macquarie Park which received an entirely new rail station. In this context, the latter could be expected to deliver greater benefit than the other locations and, as a consequence, register a larger improvement in nearby property values. This led to the second hypothesis:

H2: With the introduction of a new rail line, the change in the property premium derived from new rail accessibility will generally exceed the premium derived from augmented rail accessibility.

In this paper, it is argued that rail stations (as *places*) with sufficiently large-scale economic and social infrastructure to meet a high proportion of its community needs, provide less utility from new rail services compared with less endowed centres. This suggests new rail investments, capitalised into property values, may differ according to location type. This led to the third hypothesis:

H3: Ceteris Paribus, the additional premium paid for residential properties located close to rail stations that receive new rail infrastructure will be relatively lower in centres with greater size and variety of economic activity and community facilities, compared to those with fewer such attributes.

4.3 Analytical model

Following Grass's (1992) methodology, this study employed the hedonic pricing model to determine the effect of rail accessibility on residential property values. A log-linear specification was adopted with the dependent variable (*DV*) to enable proportionate interpretation of the results. The *DV* is represented by the adjusted transaction price of residential housing. The independent variables (*IV*s), which explain house prices, are represented by structural characteristics and accessibility. As per Grass (1992), neighbourhood attributes of impact and control areas were excluded from the model because they are perfectly collinear with location. This is justified by the high degree of homogeneity provided by close proximity and similarities of the impact/control areas.

This study investigated three spatially segmented markets, which required separate modelling for each location (Andersson, Shyr & Lee 2012). In addition, the aim to investigate changes in demand between time periods required modelling for each phase of the project (Bajic 1983; Dewees 1976; Ge, Macdonald & Ghosh 2012; Lin & Hwang 2004). Hence, a set of nine models was used to account for the effect of new rail investment on price disparity between the impact and control areas and to identify locational differences. A composite model, for each location, was also provided to further enhance analytical findings and to gauge whether the changes between impact and control variables are significant over time rather than random variations. The latter model was then modified to include a split of the impact area into two distance variables to reveal the changes occurring within the impact zone. In all cases, the aim was to generate regression functions of 'best fit'. The power and performance of the models, and relevance of the data were tested by a number of interpretation statistics.

4.4 Model interpretation statistics

Various measures were employed to test model specification and performance, and the significance of variables used in the regression analysis. The robustness of the model was determined by using measures such as White's test of standard errors for heteroscedasticity, which establishes if errors have equal variance. Tests for multicollinearity were also conducted using variance inflation factors (*VIFs*), and highly collinear predictors were excluded from the analytical process.

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

It was 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 was tested at $p < 0.10$, $p < 0.05$ and $p < 0.01$.

4.5 Data

Data samples were taken from three locations along Sydney's Epping-Chatswood rail link and their respective control areas. Secondary data were used for this research study and include Sydney residential housing market sale transactions for a 16-year period between 1998 and 2014. Data were sourced for locations in sufficient numbers to minimise the effect of the random error. Panel data arrangement was likely to be infeasible due to a lack of sufficient repeated sales over the time. Instead, the data were organized in a cross-sectional format. These data were divided into *n* different categories, of which *n-1* dummy variables were required to model the variables' effects.

To maximise compatibility of the observations used in the study, the analysis was restricted to residential units (apartments). Property transaction prices and structural characteristics of units were sourced from Australian Property Monitors (APM), one of the largest residential property databases in Australia. Unit property prices formed the *DV*, while physical characteristics of the properties, including number of bedrooms, bathrooms, parking spaces and distance from the rail station provided the basis for the *IVs*. The data set is compatible with those used in similar hedonic pricing model studies undertaken in other empirical research, although it should be noted that Australian data sources do not provide an overall measure of dwelling size, which is commonly used elsewhere. Nevertheless, number of bedrooms and bathrooms is a good proxy for unit size (Fletcher, Gallimore & Mangan 2000).

APM captures property transaction price details and physical characteristics from a number of sources, including auction results, state and local government agencies and real estate agents. APM data are a major source of housing information used by the RBA for analytical purposes. They are also used by three of Australia's four leading banks to assess the property market. Some prominent references using APM data include RBA papers by Hansen (2006) and Prasad and Richards (2008). APM data were used for articles by Kennedy (2010), from the Department of the Treasury, Australian Federal Government, and have also appeared in numerous other articles both in Australia and overseas.

Some data limitations concerning transaction prices and property details have previously been raised. The issue is that "changing characteristics of the housing stock through renovations and extensions can have a large impact on the sale price and lead to misleading data when used as an indicator of prices" (Setiadi, Atchison & Fin 2006). Although this has implications for the present research, the issue of renovations and extensions is far more relevant to freestanding residential properties. Units are rarely extended and unit renovations tend to make marginal differences to property price because the majority of property value is captured in the building within which the unit is located.

This research study may require some data cleansing. In his study of Australia house prices, Hansen (2006, p. 31) noted data provided by APM were subject to removal if the 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". He also noted a small number of observations were removed to "reduce the influence of outliers and ensure plausible estimates of the implicit price relativities" (Hansen 2006, p. 31).

Building age is considered an important factor in most studies using the hedonic pricing model for the purpose of property valuations (Debrezion, Pels & Rietveld 2007). However, this information is excluded from APM data, and as a substitute this study used strata plan registration date, available from the NSW Department of Financial Services, Lands and Property Information Division. A strata plan is usually registered for a unit complex shortly after construction and before occupancy. Hence, this date provides an excellent substitute for building age.

Building heights and floor levels are also considered an important factor in determining property values because taller structures provide views that generally command a price premium (see Section 2.3.4.3). APM does not offer appropriate information regarding floor levels. This limitation was overcome by visiting each building structure in excess of four stories to determine unit number/level details. Buildings over four stories were generally distinguished in the raw data by the large number of units in the complex, and in some instances three-digit unit numbers, the first representing floor level. Complexes potentially greater than four stories were confirmed on Google Street View and each building was personally checked to ensure an accurate record of floor level information.

This study constructed a data set of unit sale transactions collected from 1998 to currently available 2014. Data were subdivided into three periods: before construction, during construction and post opening of the Epping-Chatswood rail link. This enabled assessment of changes in property values between impact areas and their controls, during these periods. Unit sale transactions were selected from distances less than 530 metres (one-third of a mile) and between 531 and 1000 metres from the train station, representing the extent of the impact area (Dewees 1976; RICS Policy Unit 2002). Transaction details were also sourced from appropriate control locations, outside the impact areas.

4.6 Functional form

Various approaches to functional form were tested to derive the model with greatest explanatory power and estimation accuracy. These procedures included linearity, polynomial and logarithmic models. Ultimately there was little evidence to suggest the data violated multi-linear regression assumptions confirming the author's intuitive understanding of the market. Hence, the model used is based on the presumption that the *DV* has a linear relationship with its corresponding *IVs*. This is expressed in the following form:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots\ldots + \beta_n X_{ni} + e_i$$

Where:

Y = dependent variable

β_0 = constant term

β_1 = coefficient of the attribute X_1

i = observation

e_i = error term

4.7 Model variables

Residential property prices are generally determined by structural, accessibility and neighbourhood attributes (Section 2.3.4). Conceptually, the hedonic pricing model appears as:

$P = f(S, A, N)$

Where:

P = property transaction price, as a function of three categories of independent factors including:

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

A = a dummy variable relating to distance from a rail station

N = a vector of variables describing neighbourhood characteristics. In this study *N* is considered a constant (see Section 4.3)

In the interest of parsimony, this study included only *IVs* that were considered highly influential in regard to the *DV*, based on theoretical and empirical precedent. Table 5 shows both the *DV* and *IVs* chosen for the study.

Vector	Variable	Description	Source
Dwelling prices	NPRICE	Nominal transaction price	APM
	APRICE	Adjusted transaction price	Derived: APM
Structural	BED	Number of bedrooms	APM
	BATH	Number of bathrooms	APM
	CAR	Number of car spaces/garages	APM
	AGE	Age of strata title	Dept. Lands & Property
	AGE2	Age squared	Derived: Dept. Lands & Property
	LV3	Up to 3rd level	APM & physical collection
	LV9	Building levels 4 – 9 inclusive	APM & physical collection
	LV19	Building levels 10 – 19 inclusive	APM & physical collection
	LV20PL	Building level 20 plus	APM & physical collection
Accessibility	IMPCT	Impact area: Combined DS530 & DS1000	APM
	CNTRL	Control location	APM
	DS530	Between 0m and 530m to station	APM
	DS1000	Between 531m and 1000m to station	APM
Project phases	BC	Before construction	APM
	DC	During construction	APM
	PO	Post opening	APM
	SYEAR	Sale year	APM

Table 5: Description of variables

4.7.1 Dependent variable (DV)

In this study the *DV (APRICE)* was logged, which enabled interpretation of coefficients as proportionate changes attributable to predictors in the model. Dollar comparisons were also made in this study, which required taking into account inflation and fluctuations in the Sydney real estate market. This meant the *DV* needed to be standardised for property price inflation. To achieve this, prices were adjusted by applying the Sydney Established Housing Index (HPI) (ABS 2014) to the nominal unit price. The HPI covers transactions of detached residential dwellings and land (*note:* currently, the unit specified price index has insufficient coverage appropriate for this study). The adjusted price of properties was calculated by:

*APRICE = N*100/HPI*

Where:

APRICE = real price of a property at 2010 values

N = nominal price of properties

HPI = monthly price indices corresponding to the transaction date

To provide full coverage to the study period, it was necessary to convert two indices to prices equivalent at December 2010 = 100 (ABS guidelines followed).

4.7.2 Independent variables (IVs)

Both continuous and dummy variables were used in the regression model. The following discussion provides details of each variable. All variables are defined in the literature as suitable predictors of residential property price.

Structural characteristics of residences represented in the model include number of bedrooms (*BED*), bathrooms (*BATH*) and car spaces (*CAR*). The first two of these characteristics offered a suitable proxy for unit floor size, which was unavailable from transaction record data. Numerous studies indicate number of bedrooms (Fletcher, Gallimore & Mangan 2000; Li & Brown 1980) and bathrooms (Garrod & Willis 1992; Linneman 1980) are positively related to residential property values.

Age (*AGE)* of residences is likely to have an impact on property prices and was therefore included in the list of *IVs*. The literature reveals the relationship between *DV* and *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. Therefore, initially *AGE* estimates were introduced to the model as both nominal and squared values (*AGE2)*.

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 usually have a price premium attached (Benson et al. 1998). For the purpose of this study floor level was categorised into four groups comprising levels 1–3 *(LV3)*, which is most common in metropolitan units outside the CBD; levels 4–9 inclusive *(LV9)* encompassing the restricted height limits of Epping and Macquarie Park; and two further groups of 10–19 *(LV19)* and 20 plus *(LV20PL)*, which capture remaining building heights in Chatswood.

Modelling focused on the relationship between the impact *(IMPCT)* and control *(CNTRL)* variables. *IMPCT* data represent all sales transactions from the impact area during the period of study, and *CNTRL* represents corresponding data from the control area. In the absence of significant events likely to influence property prices in both the impact and control areas, apart from the introduction of new rail infrastructure in the former, changes in the relationship between *IMPCT* and *CNTRL* were reasonably assumed to be the result of new rail investment.

IVs relating to distance from the rail station, within the impact area, were included in a supplementary regression model as dummy variables. A radial distance up to 530 metres (*DS530*) is generally considered to be the walk-up zone and is potentially the area of greatest impact resulting from new rail investment (Dewees 1976). Distance from 531 to 1000 metres (*DS1000*) is considered the outer extent of the impact zone (see Section 2.2.1.4). In this supplementary model the data set was limited to the impact area and the price gradient associated with rail station access was represented by the difference between the variables *DS530* and *DS1000*. The magnitude of the distance coefficient and its sign was determined by the net effect of negative externalities generated by the rail station and the improved accessibility benefits available to residents.

Three samples comprising observations for before construction (*BC*), during construction (*DC*) and post opening (*PO*) were used to represent the various phases of the rail link project. *BC* represents a period prior to notification of tender. Notification of new rail infrastructure investment generally has a positive influence on property values nearby the potential impact zone (Gatzlaff & Smith 1993; Henneberry 1998; McDonald & Osuji 1995). In NSW, deliberations regarding new rail projects traditionally occur over a number of years and there is often some cynicism regarding government commitment to infrastructure projects. A solid indication of the start date for construction is the announcement of awarded tender, which for this project occurred in July 2002 (Thiess Constructions). *BC* phase was taken back to 1998, which is the extent of quality data available. Therefore, *BC* is the period January 1998 to July 2002.

DC represents the construction phase of the project. This is the period when communities nearby the construction areas are subject to greatest disturbance. *DC* is defined as the period immediately following awarding of the tender to the date of service commencement. The *DC* period was taken from August 2002 to February 2009 (Bibby 2009).

Service commencement, or the *PO* phase, follows the completion of construction and service testing. While developers generally respond quickly after the awarding of tender, residents and new home seekers generally warm to the benefits of a new rail service over the months and years following its opening (Gatzlaff & Smith 1993; Henneberry 1998; McDonald & Osuji 1995). For this reason the *PO* phase was taken from the March 2009 (opening) through to the current year, 2014.

4.8 Descriptive statistics

The following are the descriptive statistics for the variables related to three rail stations at Epping, Chatswood and Macquarie Park:

	Epping data sample				**Carlingford (control) data sample**			
	Mean	Std. dev	Min	Max	Mean	Std. dev	Min	Max
BED	2.24	0.50	1	4	2.26	0.54	1	4
BATH	1.25	0.43	1	2	1.75	0.44	1	3
CAR	1.13	0.34	1	4	1.48	0.52	1	3
AGE	35.45	11.83	4	52	15.21	11.46	1	46
NPRICE	$419,725	$123,912	$145,800	$1,200,000	$420,756	$116,262	$185,000	$970,000
APRICE	$510,274	$96,090	$225,000	$1,159,420	$490,609	$89,839	$186,680	$871,440

Table 6: Descriptive statistics for Epping and control data sample
Note: APRICE dollar figures standardised at 2010 prices

	Chatswood data sample				Lane Cove (control) data sample			
	Mean	Std. dev	Min	Max	Mean	Std. dev	Min	Max
BED	1.97	0.66	1	4	2.04	0.54	1	5
BATH	1.57	0.51	1	3	1.13	0.35	1	3
CAR	1.14	0.35	1	3	1.15	0.37	1	3
AGE	19.27	13.82	3	52	37.40	11.98	2	52
NPRICE	$579,115	$255,471	$183,000	$2,278,000	$425,126	$161,448	$150,000	$1,485,000
APRICE	$690,786	$248,974	$213,963	$2,376,641	$531,344	$166,961	$234,567	$1,612,318

Table 7: Descriptive statistics for Chatswood and control data sample
Note: APRICE dollar figures standardised at 2010 prices

	Macquarie Park data sample				Top Ryde (control) data sample			
	Mean	Std.dev	Min	Max	Mean	Std. dev	Min	Max
BED	1.88	0.43	1	3	1.93	0.36	1	3
BATH	1.13	0.34	1	2	1.16	0.37	1	2
CAR	1.10	0.34	1	4	1.07	0.28	1	2
AGE	35.08	8.16	6	42	34.17	11.96	2	49
NPRICE	$361,580	$108,542	$144,000	$900,000	$297,401	$116,487	$ 78,000	$687,500
APRICE	$442,371	$ 85,353	$245,262	$859,599	$391,782	$ 92,052	$165,605	$821,385

Table 8: Descriptive statistics for Macquarie Park and control data sample
Note: APRICE dollar figures standardised at 2010 prices

4.9 Equation

Models were developed for each location comprising factors that explain changes in property values and in doing so enable isolation of the rail accessibility effect. This process was undertaken for each of the three project phases outlined earlier. The explanatory power of the accessibility and other factors contributing to property price variations is encapsulated in the following equation:

$$Ln(APRICE_i) = \beta_0 + \beta_1 BED + \beta_2 BATH + \beta_3 CAR + \beta_4 AGE + \beta_5 LV9 + \beta_6 LV19 + \beta_7 LV20PL + [\beta_8 DS530] + \beta_9 IMPCT + e_i$$

Where:

APRICE	=	transaction price of the property standardised at 2010 prices
β_0	=	constant term
BED, *BATH*, *CAR*, *AGE*	=	continuous variables relating to property structure
LV9, *LV19* and *LV20PL*	=	building level variables represented by dummies, 1 if within the range and 0 otherwise (see Table 5)
DS530	=	distance variable represented by dummy, 1 if within the range and 0 otherwise (restricted to *IMPCT* data, see Table 5)
IMPCT	=	location dummy equal to 1 when the property is inside the impact area and 0 otherwise
e	=	error term

A composite model for each location comprising data across all time periods was used to test the significance of changes in the coefficients of independent variables between each phase of the rail project. Finally, a modified composite model substituting distance variables (*DS530* and *DS1000*) in place of the *IMPCT* variable was used to identify the magnitude and significance of price movements within the impact zone. *DS530* and *DS1000* are each represented by a dummy equal to 1 if a property falls within its zone and 0 if not.

4.10 Expected results

The focus of this research was to estimate the relative impact of new rail investment on property values in Epping classified as a *town centre* and Chatswood as a *major centre*. In this study, Epping and Chatswood have benefited equally from augmented rail services and factors leading to other potential variances were addressed. Given the relatively larger size and variety of its economic and community activity, it was hypothesised that a *major centre* is likely to derive less value in terms of rail accessibility than a *town centre*. Therefore, Chatswood was expected to encounter less change in property values due to new rail investment, compared with Epping.

Macquarie Park received an entirely new station (Macquarie University) as a result of the Epping-Chatswood rail link, enabling first-time rail access to the CBD. Macquarie Park is a campus-style commercial district focused on motor vehicle access, which provides direct competition to rail services and potentially moderates the value of new rail investment. Nevertheless, a greater impact on property value was expected at Macquarie Park, due to its new station, compared with Epping and Chatswood, which received augmented rail services.

The expected sign of the coefficient for *IMPCT* was unknown because it depends on the relationship between property prices in the impact and control areas. The direction of the coefficient may be negatively affected in the *DC* phase, compared with phases *BC* and *PO*, due to nuisances generated by construction. However, overall it was expected that improved accessibility offered by new rail investment would lead to an increase in property values in the impact area compared with the control, implying the *IMPCT* coefficient becomes more positive.

Structural features that reflect the size of a unit were expected to exert a positive influence on property values. These factors include number of bedrooms, bathrooms and car spaces that act as a proxy for unit floor space. Generally, the size of floor space in the Sydney market is positively related to property value because more space is perceived to deliver a superior living environment, hence greater utility for households. Therefore, the relationship between the *DV* (*APRICE*) and each *IV* (*BED*), (*BATH*) and (*CAR*) was expected to produce a positive coefficient sign.

As previously discussed, we can expect *AGE* to have a negative effect on property value (see Section 2.3.4.1). As a property ages it deteriorates, which means potentially increased strata maintenance fees will be capitalised into property values. In this study, *AGE2* did not contribute to model performance and was excluded. The sign reflecting the relationship between *AGE* and the *DV* was expected to be negative.

A higher floor level is generally expected to increase the value of a property, although the increment is unlikely to be monotonic, rather increasing at a decreasing rate. In general, views are considered an important driver of property values in Sydney, which may vary according to the aspect. In this study, the relationship between level and the *DV* (*APRICE*) was expected to deliver a positive sign.

The coefficient of the distance variable *DS530*, relative to the base case *DS1000*, reflects the perceived benefit of closer proximity to the rail station. The sign of the coefficient for *DS530* largely depends on the net effect of positive and negative externalities generated from the new rail investment having an effect on closer proximity to the rail station. The sign of the coefficient for *DS530* is not easily predicted.

The expected signs of coefficients corresponding to the various model factors are summarised in Table 9.

Independent variable	**Expected coefficient sign**	**Base case**
BED	POSITIVE (+ve)	
BATH	POSITIVE (+ve)	
CAR	POSITIVE (+ve)	
AGE	NEGATIVE (-ve)	
LV9	POSITIVE (+ve)	LV3
LV19	POSITIVE (+ve)	LV3
LV20PL	POSITIVE (+ve)	LV3
IMPCT	UNKNOWN	CNTRL
DS530	UNKNOWN	DS1000

Table 9: Expected sign of coefficients in all models

The next chapter shows the results of the empirical analysis following application of the methodology described in this chapter. These results are then reviewed, interpreted and compared with the expectations outlined above.

Chapter 5: Results and interpretation

In this chapter, the empirical results of the models are presented and discussed. The primary objective was to compare property value changes at Epping (*town centre*) and Chatswood (*major centre*) due to the introduction of additional rail services in these communities. This was determined by estimating the change in the proximity premium for each location between three phases of the new rail link project, before construction (*BC),* during construction *(DC)* and post opening (*PO)*. In addition, the change in proximity premium for Macquarie Park was calculated to establish the effect of a new station on property values. Finally, the study examined the influence of rail investment on property prices within the rail catchment area of each location.

Sections 5.1, 5.2 and 5.3 show the results of regression analysis for Epping, Chatswood and Macquarie Park and Section 5.4 provides a comparison of estimates of across locations. Initial data cleansing was conducted to remove transactions with incomplete records (see Section 4.5). Casewise diagnostics was employed to detect outliers by setting standard deviations within three units. This was followed by an assessment of influential observations using leverage values. As a result, a number of properties subject to misclassification were identified and removed from the sample data. Perfectly collinear variables associated with neighbourhood characteristics of the impact and control areas were also omitted from modelling (see Section 4.3) and the variance inflation factor (VIF) was applied to test for significant multicollinearity issues. Finally, White's Test of standard errors was used to assess heteroscedasticity, and where found, HC standard errors were applied to reduce coefficient estimate bias.

A theoretically specified model was used in this analysis and conducted separately for each of the three locations (see Section 4.3). Modelling for each location was conducted in four stages. First, a preliminary analysis tested the price stability of the respective control areas to ensure changes attributed to rail investment were not biased as a result of property value movements in the control area (Grass 1992). The absence of significant price changes in the control area meant its prices were consistent with the general housing market and were therefore a good reflection of the cost of home ownership in an area similar to the impact area, but without the benefit of convenient rail access. Control area property price trends were determined by regressing property transaction prices against year of sale during the study period.

The second stage of the analytical process compared separate hedonic price estimates for each phase of the rail project (Bajic 1983; Dewees 1976; Lin & Hwang 2004). This set of models included the *IMPCT* variable with *CNTRL* used as the base case to reveal the magnitude of the difference between these variables at each phase of the rail project. All other structural variables were used in this stage of the analytical process apart from building levels which were included only if applicable. In addition, stepwise analysis found *AGE2* contributed no additional value and therefore omitted from modelling, while *AGE* was significant and retained.

The third stage of the analytical process involved a composite model comprising data across all time periods. This enhancement to the standard analytical practice enabled a test of significance in regard to changes in unit sale prices between each phase of the rail project. The composite model required additional formulated variables, which are explained in Section 5.1.2.

Finally, the composite model outlined above was modified to include distance variables. This involved replacing the *IMPCT* variable with its component parts, comprising the inner distance (*DS530)* and outer distance (*DS1000)* variables and restricting the data set to the impact area (*IMPCT*) only. The purpose of the composite distance model was to estimate the extent of price shifts within the impact area.

5.1 Epping

Following the analytical process outlined above the first task was to investigate property price stability in the control area. Price variations across the study period were tested to ensure changes in residential unit prices could be attributed to an event in the impact area and not due to changes in the control area. The results of this test are shown in Table 10.

Carlingford *DV = Ln(APRICE)*					
Variables	Coefficient	Std. error	t-ratio	p-value	
Constant	9.77428	3.18568	3.0680	0.0022	***
SYEAR	0.00165	0.00158	1.0400	0.2988	
Observations	716				
*** significant at 1%; ** significant at 5%; * significant at 10%					

Table 10: Carlingford annual sales price movement

Table 10 shows no significant change in the adjusted transaction prices at Carlingford during the study period. This suggests Carlingford is typical of the broader community in regard to property price changes during the study period, and therefore provides a suitable control base. As a result, estimations shown in Table 11 may be considered reliable indicators of changes to property valuations due to an event in the impact area.

5.1.1 Regression results for each project phase

Three hedonic pricing regressions were estimated separately for the periods *BC*, *DC* and *PO*. Building level variables were excluded from the model because of the small number of observations and lack of contributing value. The OLS estimates of variables influencing property prices for each period are shown in Table 11.

	Epping-Carlingford: *DV = Ln(APRICE)*					
Variables	Before construction (*BC*)		During construction (*DC*)		Post opening (*PO*)	
Constant	12.08491 (0.0354)	***	12.63780 (0.0284)	***	12.65490 (0.0247)	***
BED	0.13337 (0.0134)	***	0.10119 (0.0102)	***	0.09259 (0.0088)	***
BATH	0.06222 (0.0158)	***	0.08154 (0.0133)	***	0.09770 (0.0121)	***
CAR	0.01772 (0.0175)		0.07025 (0.0119)	***	0.08089 (0.0101)	***
AGE	-0.00676 (0.0005)	***	-0.00646 (0.0005)	***	-0.00411 (0.0004)	***
IMPCT	**0.17056 (0.0149)**	***	**0.22890 (0.0120)**	***	**0.24992 (0.0108)**	***
R^2	0.491361		0.552005		0.559368	
Adjusted R^2	0.486234		0.549107		0.556904	
P-value (F)	1.59e-70		3.9e-132		2.4e-156	
Observations	502		779		900	
Standard errors in parentheses. *** significant at 1%; ** significant at 5%; * significant at 10%						

Table 11: Epping-Carlingford independent variable coefficients

Across the time periods, the hedonic pricing models while statistically significant do not fully explain the variation in the dependent variables. Additional unmeasured variables, which also have significant roles in price determination, may be absent from the models. This may give rise to the possibility of omitted variable bias (OVB). However, the model specification is consistent with previous theoretical and empirical studies (Dewees 1976; Garrod & Willis 1992; Grass 1992). With these observations in mind, the hedonic pricing model analysis reveals the following key findings:

i) The five identified variables (*BED, BATH, CAR, AGE* and *CNTRL*) in the models explain 49%, 55% and 56% of the variation in adjusted transaction prices in the periods *BC, DC* and *PO* respectively.

ii) The coefficient signs generated by the Epping/control model are largely consistent with expectations (Section 4.10). Over the three periods, the variables *BED, BATH CAR, AGE* and *IMPCT* are all highly significant apart from *CAR* in the period *BC*, which is not significant at any level.

iii) The impact area (*IMPCT*) registered an initial premium of 17.1% during the period *BC*. For control residents this figure demonstrates the cost avoided by residing just beyond a rail catchment zone. By *PO* the premium had risen to 25.0%, which suggests a substantial rise in the value of Epping property prices as a result of the rail project. The regression model also reveals adjusted prices for the impact area improved relative to the control area throughout the three phases, indicating negative externalities associated with construction had no affect on the perceived value of the new rail service (see Figure 8).

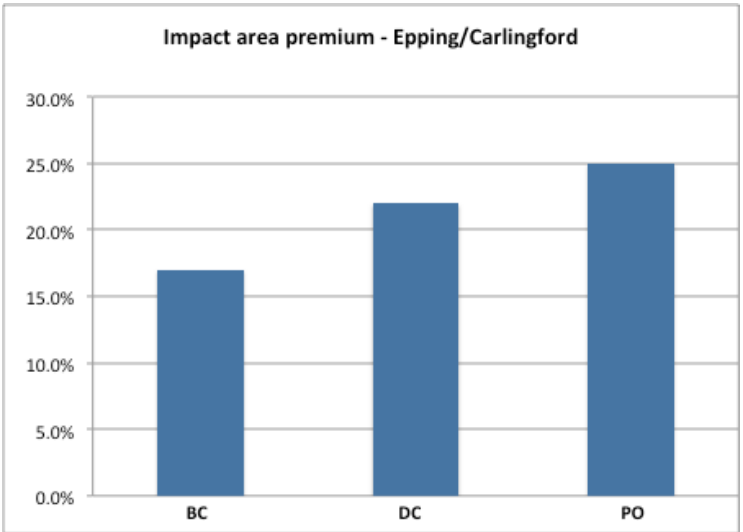

Figure 8: Impact area premium: Epping-Carlingford

5.1.2 Composite model with impact variable

The third step in the analytical process involved a composite model combining time periods *BC*, *DC* and *PO* into a single regression. The benefit of the composite model is that it identifies the significance of changes in key variables between phases of the rail project. Additional formulated time-split variables used to construct the composite model are the product of the original *IV*s split according to the period of observation (see Appendix B: Formulation of time split variables).

Table 12 shows the results of the Epping-Carlingford composite hedonic pricing model. An *F-test* [F(12, 2165) = 131.63] confirmed the time split variables added value to the model, compared with a basic model populated with structural features and *IMPCT* (significant at the 1% level). The adjusted R^2 shows the model explains 59% of variation in the dependent variable, which although higher than the average across time periods shown in Table 11, may still present the possibility of some OVB. Nevertheless, the model is considered suitable to test if changes to the magnitude of coefficients shown in Table 12 are significantly different from zero.

Epping-Carlingford: *DV = Ln(APRICE)*					
Variable	Coefficient	Std. Error	t-ratio	p-value	
const	12.8491	0.0352778	364.2256	<0.00001	***
BED	0.133374	0.0133066	10.0231	<0.00001	***
BATH	0.0622175	0.0156989	3.9632	0.00008	***
CAR	0.0177162	0.017385	1.0191	0.30829	
AGE	-0.00676361	0.000550108	-12.2951	<0.00001	***
IMPCT	**0.170563**	**0.0148391**	**11.4942**	**<0.00001**	***
IMPTDC	**0.0583427**	**0.0191068**	**3.0535**	**0.00229**	***
IMPTPO	**0.0793601**	**0.0183503**	**4.3247**	**0.00002**	***
DC	-0.211227	0.045295	-4.6634	<0.00001	***
PO	-0.194123	0.0431194	-4.5020	<0.00001	***
DCBED	-0.0321829	0.0167677	-1.9193	0.05507	*
POBED	-0.0407871	0.0159841	-2.5517	0.01079	**
DCBATH	0.0193204	0.0205491	0.9402	0.34722	
POBATH	0.0354818	0.0198229	1.7899	0.07360	*
DCCAR	0.0525376	0.0210655	2.4940	0.01271	**
POCAR	0.0631729	0.0201386	3.1369	0.00173	***
DCAGE	0.000304348	0.000714895	0.4257	0.67035	
POAGE	0.00264867	0.000691099	3.8326	0.00013	***

*** significant at 1%; ** significant at 5%; * significant at 10%

R^2	0.597042	Adjusted R^2	0.593875
F(17, 2163)	188.5178	P-value(F)	0.000000
Observations	2,181		

Table 12: Epping-Carlingford composite

The composite model reflects changes in lifestyle preferences and willingness to pay for transport accessibility. For example, an additional bedroom cost 13.3% or $67,158 (based on average prices in 2010) during the period *BC*, while valued less at 9.26% or $46,653 in the *PO* period (significant at the 1% and 5% level, respectively). In contrast, an additional bathroom cost 6.2% ($31,346) *BC* compared with 9.76% ($48,971) in the period *PO* (at the 1% and 10% level, respectively). However, the most dramatic change in residence preferences affected car spaces and building age. Additional car spaces *BC* were not considered valuable, while in the *PO* period homebuyers were willing to pay 6.32% ($31,827) for an extra space (at the 1% level). In regard to building age the value of an average unit depreciated by 0.67% ($3,375) annually *BC*, although by *PO* homebuyers were much less concerned with building age and building price depreciation dropped to 0.41% ($2,045) annually (both at the 1% level). Controlling for changes in structural features the composite model indicates the premium associated with rail accessibility (*IMPCT*) during the period *BC* was 17.1% ($86,152), rising to 22.8% *DC* ($115,122) and 24.9% *PO* ($125,702) (all at the 1% level).

5.1.3 Composite model with distance variables

The final stage of location modelling tested the effect of distance from the rail station on property prices within the impact area (Table 13). In this variation of the composite model the base case was *DS1000*, which means the coefficient of the dummy variable *DS530* represents its implicit price relative to that of *DS1000*. As expected, the effect of dividing the impact area into two distance variables *DS530* and *DS1000* and limiting the data set to *IMPCT* altered some of the property structure coefficients in the model previously estimated in Table 11. However, the primary focus of this model is to identify shifts in value between the inner and outer zone of the impact area.

Epping: *DV = Ln(APRICE)*					
Variable	Coefficient	Std. error	t-ratio	p-value	
Constant	12.9602	0.0448506	288.9629	<0.00001	***
BED	0.161208	0.0148687	10.8421	<0.00001	***
BATH	0.0367249	0.0191189	1.9209	0.05495	*
CAR	0.0293137	0.0242597	1.2083	0.22712	
AGE	-0.0066639	0.00060357	-11.0408	<0.00001	***
DS530	**0.0162217**	**0.0149598**	**1.0843**	**0.27839**	
DC530	**0.0275905**	**0.0188705**	**1.4621**	**0.14393**	
PO530	**0.007104**	**0.0202394**	**0.3510**	**0.72564**	
DC	-0.180821	0.0566679	-3.1909	0.00145	***
PO	-0.154601	0.0582086	-2.6560	0.00799	***
DCBED	-0.0204347	0.0193216	-1.0576	0.29041	
POBED	-0.0366698	0.0192035	-1.9095	0.05639	*
DCBATH	0.0356516	0.0246155	1.4483	0.14774	
POBATH	0.06131	0.024622	2.4901	0.01288	**
DCCAR	0.00740365	0.0289318	0.2559	0.79806	
POCAR	0.0259156	0.0286382	0.9049	0.36565	
DCAGE	0.000643662	0.000794188	0.8105	0.41781	
POAGE	0.00364502	0.000796285	4.5775	<0.00001	***

*** significant at 1%; ** significant at 5%; * significant at 10%

R^2	0.588271	Adjusted R^2	0.583434
F(17, 2163)	121.6147	P-value(F)	5.8e-264
Observations	1,465		

Table 13: Epping composite distance

The results of the composite distance model for Epping reveal a positive sign for the variable *DS530* in each period, indicating a small premium for properties closer to the station compared with those further away in the impact area. This is consistent with much of the literature concerning price decay with further distance from the rail station. However, it should be noted that the absence of statistical significance for distance variables in all periods suggests these observations are inconclusive. The results also show there is no discernable change in the movement of property values between *DS530* and *DS1000*, due to rail investment at Epping.

5.2 Chatswood

Following the procedure adopted in Section 5.1, the first task was to assess the stability of property prices of Chatswood's control location at Lane Cove. A possible confound for the

Chatswood model, in terms of identifying the impact of rail investment, was the opening of the Chatswood-Lane Cove motorway tunnel in 2007. The concern is the tunnel may have the potential to favour residents of Lane Cove, as it is substantially closer to this suburb. This would have the effect of boosting Lane Cove's accessibility premium and therefore skewing the estimates of property value changes as a result of the new rail service at Chatswood. However, Table 14 clearly demonstrates there is no discernible change in control area property prices throughout the period of the research study. This means Lane Cove remains a legitimate control location to estimate the effect of rail investment on property values in Chatswood.

Lane Cove *DV = Ln(APRICE)*					
Variables	Coefficient	Std. error	t-ratio	p-value	
Constant	16.5337	3.31930	4.981	7.33e-07	***
SYEAR	-0.00168836	0.00165461	-1.020	0.3078	
Observations	1,110				
*** significant at 1%; ** significant at 5%; * significant at 10%					

Table 14: Lane Cove annual sales price movement

5.2.1 Regression results for each project phase

Three hedonic pricing models were conducted separately for the periods *BC*, *DC* and *PO*. Unlike Epping, the Chatswood-Lane Cove district contains a multitude of tall residential buildings with the potential to influence unit prices, and therefore it was appropriate to include building height variables in the Chatswood model (Section 2.3.4.3). Discernable differences in unit floor height are most likely identifiable at particular discrete intervals, which were included in the model (Section 4.7.2). The OLS estimates of all variables influencing property prices for each period are shown in Table 15.

	Chatswood-Lane Cove: *DV = Ln(APRICE)*					
Variables	Before construction (*BC*)		During construction (*DC*)		Post opening (*PO*)	
Constant	12.79410 (0.03653)	***	12.55820 (0.02852)	***	12.54970 (0.02299)	***
BED	0.16506 (0.01494)	***	0.19445 (0.01152)	***	0.19101 (0.01036)	***
BATH	0.16893 (0.02073)	***	0.14851 (0.01528)	***	0.12680 (0.01319)	***
CAR	0.09069 (0.02118)	***	0.08533 (0.01618)	***	0.11421 (0.01375)	***
AGE	-0.00538 (0.00058)	***	-0.00386 (0.00046)	***	-0.00133 (0.0004)	***
LV9	0.12466 (0.02009)	***	0.07893 (0.01403)	***	0.09582 (0.01277)	***
LV19	0.19079 (0.02160)	***	0.08737 (0.01526)	***	0.12147 (0.01397)	***
LV20PL	0.30815 (0.03422)	***	0.22026 (0.02405)	***	0.38849 (0.01651)	***
IMPCT	**0.04433 (0.01553)**	***	**0.02725 (0.01306)**	**	**0.09473 (0.01231)**	***
R^2	0.757703		0.682358		0.776719	
Adjusted R^2	0.754969		0.680333		0.775373	
P-value (F)	1.9e-212		3.9e-306		0.000000	
Observations	718		1,264		1,336	

Standard errors in parentheses. *** significant at 1%; ** significant at 5%; * significant at 10%

Table 15: Chatswood-Lane Cove independent variable coefficients

Table 15 shows each model is significant at the 1% level, indicating the relationship between the response variables and the set of predictors is statistically reliable. The following are key findings of the three regression models:

i) Eight variables were used in the models (*BED, BATH, CAR, AGE, LV9, LV19, LV20PL* and *IMPCT*), which explained 76%, 68% and 78% of the variation in adjusted transaction prices during the periods *BC, DC* and *PO* respectively.

ii) All variables were significant at the 1% level during each period, apart from *IMPCT* in the period *DC*, which was significant at the 5% level. Similar to Epping the results for Chatswood-Lane Cove were generally consistent with expectations

iii) Higher floor levels were strongly correlated with property value. For example *LV9, LV19* and *LV20PL* were 9.6%, 12.1% and 38.8% higher than corresponding prices for *LV3* units in the period *PO*. High-rise living is a feature of Chatswood's residential occupancy and the results suggest views in this area attract a substantial property premium.

iv) *IMPCT* was 4.4% *BC,* which is lower than the equivalent measure at Epping suggesting residents in the Chatswood-Lane Cove district value rail accessibility less than their counterparts at Epping. The model also shows adjusted prices for the impact area reduced relative to the control area in the *DC* phase, which is consistent with negative externalities adversely affecting property prices during the construction phase (see Figure 9). The coefficient for *IMPCT* in the *DC* phase is also less significant, which reflects its closer approximation to zero during this period. By *PO* the *IMPCT* registered 9.5% *PO* suggesting a rise in the adjusted value of Chatswood properties relative to Lane Cove.

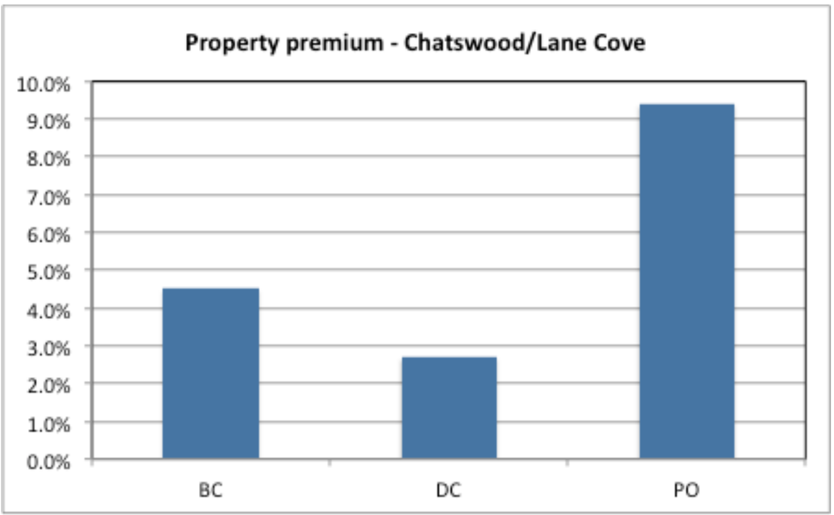

Figure 9: Impact area premium: Chatswood-Lane Cove

5.2.2 Composite model with impact variable

Step three in the analytical process involved a composite model combining time periods *BC*, *DC* and *PO* into a single regression (see Table 16). The composite model identifies the significance of changes in key variables between phases of the rail project and includes time split variables replicating the process used in the Epping analysis. An *F-test* [F(18, 3318) = 130.95] confirms the time split variables add value to the model, compared with a basic model comprising structural features and *IMPCT* only (at the 1% level). The adjusted R^2 suggests the model explains 76% of variation in the dependent variable, which is considerably higher than that observed in the Epping analysis.

Chatswood-Lane Cove: *DV = Ln(APRICE)*					
Variable	Coefficient	Std. Error	t-ratio	p-value	
const	12.7941	0.036462	350.8877	<0.00001	***
BED	0.165062	0.0149094	11.0710	<0.00001	***
BATH	0.168926	0.0206949	8.1627	<0.00001	***
CAR	0.0906974	0.0211449	4.2893	0.00002	***
AGE	-0.00538553	0.000580844	-9.2719	<0.00001	***
LV9	0.124658	0.0200577	6.2150	<0.00001	***
LV19	0.190797	0.0215686	8.8460	<0.00001	***
LV20PL	0.308154	0.0341588	9.0212	<0.00001	***
IMPCT	**0.0443358**	**0.0155001**	**2.8604**	**0.00426**	***
IMPTDC	**-0.0170833**	**0.0199956**	**-0.8544**	**0.39297**	
IMPTPO	**0.0503929**	**0.0200676**	**2.5112**	**0.01208**	**
DC	-0.235838	0.0457246	-5.1578	<0.00001	***
PO	-0.244378	0.0435467	-5.6119	<0.00001	***
DCBED	0.0293863	0.0186156	1.5786	0.11453	
POBED	0.0259479	0.0183701	1.4125	0.15790	
DCBATH	-0.0204134	0.0254339	-0.8026	0.42226	
POBATH	-0.0421229	0.0247937	-1.6989	0.08943	*
DCCAR	-0.00535755	0.0263099	-0.2036	0.83865	
POCAR	0.0235115	0.0254889	0.9224	0.35638	
DCAGE	0.00152107	0.000733565	2.0735	0.03820	**
POAGE	0.0040583	0.00070064	5.7923	<0.00001	***
DCLV9	-0.0457278	0.0242172	-1.8882	0.05908	*
POLV9	-0.0288412	0.0240234	-1.2005	0.23001	
DCLV19	-0.103428	0.0261372	-3.9571	0.00008	***
POLV19	-0.0693274	0.0259718	-2.6693	0.00764	***
DCLV20PL	-0.0878921	0.0413308	-2.1266	0.03353	**
POLV20PL	0.0803367	0.0381968	2.1032	0.03552	**

*** significant at 1%; ** significant at 5%; * significant at 10%

R^2	0.759675	Adjusted R^2	0.757777
$F(26, 3291)$	400.1143	P-value(F)	0.000000
Observations	3,318		

Table 16: Chatswood-Lane Cove composite

Table 16 composite model for Chatswood-Lane Cove identifies if changes in homebuyer preferences for property features and rail accessibility occurred across the three phases of the rail project. In this district, during the period *BC* an extra bedroom cost an additional 16.5% or $105,178 based on average prices in 2010 (at the 1% level), and there was no significant change to this premium in the periods *DC* and *PO*. Similarly, an additional bathroom cost

16.9% or $107,728 in the period BC (at the 1% level). However, unlike bedrooms the premium for an additional bathroom fell to 12.6% or $80,892 in the *PO* period (at the 10% level). An additional car space increased the premium on a residence by 9.1% or $58,007 in the period *BC*, and no significant change to this premium was evident *DC* and *PO*. Changes in discount due to building age followed a similar pattern to that in Epping-Carlingford. The value of an average unit in the Chatswood-Lane Cove district depreciated by 0.53% or $3,378 annually *BC* (at the 1% level), although by *PO* homebuyers were far less concerned with building age as annual depreciation dropped to 0.13% ($828) (at the 5% level). There was also some change in pattern of premiums regarding building level. In the period *BC* levels up to 9, 10–19 and 20 plus commanded premiums of 12.4% ($79,043), 19.1% ($121,752) and 30.8% ($196,333) respectively (all at the 1% level), relative to those at 3 levels or less. However, premiums for levels 10–19 dropped by 6.9% by the period *PO* (at the 1% level) and levels 20 plus gained 8.0% by the *PO* phase (at the 5% level). This suggests the growing importance of new 20 plus level buildings in the district, relative to those with levels between 10 and 19. Controlling for changes in structural features, the composite model shows the premium associated with rail accessibility during the period *BC* was 4.4% or $28,047 (at the 1% level), with no significant change in the period *DC*, but rising to 9.5% or $60,302 in the period *PO*, confirming the estimated change in Table 16 at the 5% level.

5.2.3 Composite model with distance variables

The composite model with distance variables tests the change in property premium between two zones within the impact area, represented by *DS530* and *DS1000*. In this model the base case is *DS1000*, which means the coefficient of the dummy variable *DS530* represents the implicit price of properties in this area relative to *DS1000*. Also the data set is limited to the impact area only. The results of the model comprising distance variables are shown in Table 17.

Chatswood: *DV = Ln(APRICE)*					
Variable	Coefficient	Std. error	t-ratio	p-value	
Constant	12.9121	0.0479782	269.1243	<0.00001	***
BED	0.176325	0.0206906	8.5220	<0.00001	***
BATH	0.114266	0.0259513	4.4031	0.00001	***
CAR	0.0170213	0.0282358	0.6028	0.54669	
AGE	-0.0054	0.00081788	-6.6024	<0.00001	***
DS530	**0.0888823**	**0.0237444**	**3.7433**	**0.00019**	***
DC530	**0.0138785**	**0.0285187**	**0.4866**	**0.62656**	
PO530	**0.015113**	**0.0284217**	**0.5317**	**0.59496**	
LV9	0.108926	0.0222517	4.8952	<0.00001	***
LV19	0.194342	0.0244515	7.9481	<0.00001	***
LV20PL	0.321504	0.0358854	8.9592	<0.00001	***
DC	-0.269175	0.0576068	-4.6726	<0.00001	***
PO	-0.292671	0.0549317	-5.3279	<0.00001	***
DCBED	0.05666	0.0252666	2.2425	0.02503	**
POBED	0.0465349	0.0248142	1.8753	0.06088	*
DCBATH	-0.0207767	0.0315939	-0.6576	0.51085	
POBATH	-0.0285869	0.030583	-0.9347	0.35003	
DCCAR	-0.0122972	0.0346301	-0.3551	0.72255	
POCAR	0.0661899	0.0336689	1.9659	0.04944	**
DCAGE	0.000455776	0.000990369	0.4602	0.64541	
POAGE	0.00370164	0.000941204	3.9329	0.00009	***
DCLV9	-0.0619916	0.0265646	-2.3336	0.01971	**
POLV9	-0.0381077	0.0260975	-1.4602	0.14438	
DCLV19	-0.135308	0.0292622	-4.6240	<0.00001	***
POLV19	-0.100579	0.028995	-3.4688	0.00053	***
DCLV20PL	-0.123286	0.043221	-2.8525	0.00438	***
POLV20PL	0.0369669	0.0403177	0.9169	0.35930	

*** significant at 1%; ** significant at 5%; * significant at 10%

R^2	0.759675	Adjusted R^2	0.757777
F(26, 3291)	400.1143	P-value(F)	0.000000
Observations	3,318		

Table 17: Chatswood composite distance

Splitting the impact area into two zones and limiting the data set to the impact area only slightly alters the magnitude of coefficients compared with those estimated in the previous table. With regard to the relative value of properties within the impact area the results indicate an 8.9% premium for those residences close to the station compared with those further away (at the 1% level). This is consistent with the literature that generally predicts price decay with further distance from the rail station. Similar to Epping the results for variables *DC530* and

PO530 indicate no significant change in the relationship between prices in the inner compared with the outer zone of the impact area. This suggests the introduction of augmented rail services that do not improve access to the CBD has no affect on the relative prices of properties within the impact area.

5.3 Macquarie Park

Investigating the impact of new rail infrastructure on Macquarie Park property values provides a basis for comparing the results of a new rail station with those due to augmented services at Epping and Chatswood. Analysis of Macquarie Park follows the process used for the preceding locations, beginning with an evaluation of price stability of the control location.

Again, there appears to be a good reason to investigate the possible existence of a confound factor that may influence property prices at Top Ryde, similar to that expected in the Lane Cove analysis. A possible 'shock' occurred with the opening of a new major shopping mall at Top Ryde, which began trading in stages between November 2009 and August 2010. These dates correspond with the *PO* period of the new rail project and may influence findings with respect to the *PO IMPCT* coefficient in subsequent analysis. To test the stability of Top Ryde as a control location changes in the district's property prices during the *PO* phase of the project were examined, which is the most likely period to exhibit effects of the new shopping mall. The results of this investigation, shown in Table 18, reveal a highly significant uplift in prices amounting to 3% per annum, which potentially underestimates the magnitude of the *IMPCT–CNTRL* relationship (see Appendix C). This prompts the need for an alternative control location.

Top Ryde *DV = Ln(APRICE)* - restricted to period PO					
Variable	Coefficient	Std. error	t-ratio	p-value	
Constant	-47.84460	21.6538	-2.2095	0.02840	**
SYEAR	0.03021	0.0108	2.8064	0.00556	***
Observations	182				
*** significant at 1%; ** significant at 5%; * significant at 10%					

Table 18: Top Ryde annual sales price movement

With limited options in the immediate Macquarie Park area investigations revealed an alternative, though more distant, control location at Brookvale. The choice of Brookvale is supported by Grass's (1992) approach, which involves selecting control areas that are similar and economically stable, though some are several kilometres from the impact area. The Brookvale locality provides a suitable alternative control area as it has demonstrated housing price stability (Table 19) and offers similar characteristics to Macquarie Park. These characteristics include a substantial employment zone, shopping mall and a large educational complex (TAFE). Brookvale is also without a train station, which is the preferred case for the model.

Brookvale *DV = Ln(APRICE)*					
Variable	Coefficient	Std. error	t-ratio	p-value	
Constant	17.33670	3.3280	5.209	2.50e-07	***
SYEAR	-0.00211	0.0016	-1.277	0.2019	
Observations	699				
*** significant at 1%; ** significant at 5%; * significant at 10%					

Table 19: Brookvale annual sales price movement

Having satisfied the requirement for price stability and given the lack of options the analysis proceeded with Brookvale as control area for Macquarie Park. However, as a cautionary note it should be emphasised that due to the distance separating the two locations the relationship between Macquarie Park and Brookvale property prices does not reliably reflect the premium paid for close proximity to the rail station compared with a home just outside the rail catchment area, which is the case for the previous location analyses. Nevertheless, while conclusions cannot drawn regarding the magnitude of the estimated property price relationship between *IMPCT–CNTRL,* it is entirely appropriate to report on changes that occurred between the periods *BC*, *DC* and *PO* (see Appendix D for descriptive statistics).

5.3.1 Regression results for each project phase

Hedonic pricing models were conducted separately for the periods *BC*, *DC* and PO. Unlike the Chatswood-Lane Cove district, Macquarie Park-Brookvale contains far fewer tall residential buildings, and height restrictions in the latter mean that building level observations are no greater than 9 levels. Hence, the variables used in the Macquarie-Brookvale model are similar to those used in the Epping model, with the addition of *LV9*. Table 20 shows the results of regression analysis for Macquarie Park-Brookvale.

Macquarie Park-Brookvale control: *DV = Ln(APRICE)*						
Variables	Before construction (BC)		During construction (DC)		Post opening (PO)	
Constant	12.85530 (0.04004)	***	12.69260 (0.02395)	***	12.66220 (0.02349)	***
BED	0.18283 (0.01316)	***	0.23094 (0.01006)	***	0.19308 (0.01047)	***
BATH	0.12003 (0.02088)	***	0.04278 (0.01345)	***	0.07269 (0.01424)	***
CAR	0.01726 (0.09018)		0.03262 (0.01229)	***	0.03561 (0.01037)	***
AGE	-0.00719 (0.00070)	***	-0.00816 (0.00053)	***	-0.00534 (0.00052)	***
LV9	0.07971 (0.02325)	***	0.04471 (0.02161)	**	0.02131 (0.01955)	
IMPCT	**-0.08758 (0.01555)**	***	**-0.02851 (0.01379)**	**	**0.06563 (0.01420)**	***
R^2	0.724919		0.767418		0.648566	
Adjusted R^2	0.720823		0.765238		0.645625	
P-value (F)	1.2e-109		6.1e-199		4.2e-159	
Observations	410		647		724	

Standard errors in parentheses. *** significant at 1%; ** significant at 5%; * significant at 10%

Table 20: Macquarie Park-Brookvale independent variable coefficients

As mentioned earlier Macquarie Park and Brookvale are separated by considerable distance and do not represent an integrated community, which suggests drawing conclusions with respect to changes in preferences for property features based on an average of the two locations, should be avoided. Nevertheless, observations concerning changes to the impact area are pertinent to this research. In this regard the key features of the regression analysis for Macquarie Park-Brookvale are as follows:

i) The Adjusted R^2 shows six *IVs* (*BED, BATH, CAR, AGE, LV9* and *IMPCT*) included in the models explain 72%, 77% and 65% of the variation in adjusted transaction prices during the periods *BC, DC* and *PO* respectively.

ii) During the period *BC* there was no train station at Macquarie Park and lifestyle preferences, probably related to coast proximity, delivered Brookvale a relative property price premium. However, between the periods *BC* and *PO* the coefficient of the *IMPCT* variable changed signs suggesting Macquarie Park's new station was influential in reversing Brookvale's relative property price premium into a property price discount (see Figure 10).

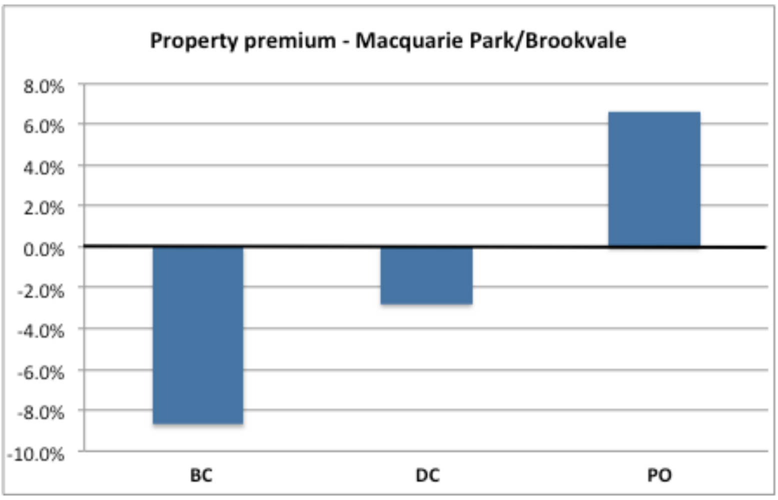

Figure 10: Impact area premium: Macquarie Park-Brookvale

5.3.2 *Composite model with impact variable*

The next analytical step combines time periods *BC*, *DC* and *PO* into a composite model (see Table 21). An *F-test* [F(14, 1781) = 123.54] confirms the time split variables add value to the model, compared with a basic model comprising structural features and *IMPCT* only. The adjusted R^2 suggests the model explains 73% of variation in the dependent variable, which is similar to the Chatswood-Lane Cove analysis.

Macquarie Park-Brookvale: *DV = Ln(APRICE)*					
Variable	Coefficient	Std. Error	t-ratio	p-value	
Constant	12.8553	0.0389284	330.2299	<0.00001	***
BED	0.182834	0.0127963	14.2880	<0.00001	***
BATH	0.120031	0.0202956	5.9141	<0.00001	***
CAR	0.0172655	0.0196244	0.8798	0.37909	
AGE	-0.00719321	0.000681531	-10.5545	<0.00001	***
LV9	0.0797103	0.0226047	3.5263	0.00043	***
IMPCT	**-0.0875843**	**0.0151214**	**-5.7921**	**<0.00001**	***
IMPTDC	**0.05907**	**0.0209335**	**2.8218**	**0.00483**	***
IMPTPO	**0.153218**	**0.0205176**	**7.4676**	**<0.00001**	***
DC	-0.162752	0.0463354	-3.5125	0.00046	***
PO	-0.193118	0.0451848	-4.2740	0.00002	***
DCBED	0.0481037	0.01659	2.8996	0.00378	***
POBED	0.0102455	0.0163818	0.6254	0.53178	
DCBATH	-0.0772526	0.0247208	-3.1250	0.00181	***
POBATH	-0.0473416	0.024604	-1.9241	0.05450	*
DCCAR	0.0153573	0.0234857	0.6539	0.51326	
POCAR	0.0183482	0.0220837	0.8308	0.40617	
DCAGE	-0.000965511	0.00088002	-1.0971	0.27273	
POAGE	0.00185709	0.000850009	2.1848	0.02904	**
DCLV9	-0.0349984	0.0320144	-1.0932	0.27445	
POLV9	-0.058404	0.0295851	-1.9741	0.04853	**
*** significant at 1%; ** significant at 5%; * significant at 10%					
R^2	0.731609	Adjusted R^2	0.728559		
F(20, 1760)	239.8802	P-value(F)	0.000000		
Observations	1,781				

Table 21: Macquarie Park-Brookvale composite

The composite model is designed to reveal changes in homebuyer preferences for property features and rail accessibility during the research period. However, due to the divide between communities observations were restricted to matters pertinent to the relationship between *IMPCT* and *CNTRL* and the influence of rail investment. In this regard, Table 21 shows, controlling for changes in structural features, Brookvale commanded an 8.7% premium over Macquarie Park in the period *BC*, which was later reversed in the periods *DC* and *PO* when the anticipation and subsequent introduction of a new rail station generated premiums favouring Macquarie Park by 5.9% and 15.3% respectively (all at the 1% level). The magnitude of changes to premiums (15.3% in favour of Macquarie Park) demonstrates the considerably greater influence a new station, with first time rail access to the CBD, has on property prices compared with the effect of augmented rail services, without improved CBD access, experienced in Epping and Chatswood.

5.3.3 Composite model with distance variables

The composite model with distance variables tests the change in property premium between two zones within the impact area, represented by *DS530* and *DS1000*. *DS1000* is used as the base case, and the data set is limited to the impact area only. The results of this model are shown in Table 22.

Macquarie Park: *DV = Ln(APRICE)*					
Variable	Coefficient	Std. error	t-ratio	p-value	
Constant	12.6963	0.0719139	176.5486	<0.00001	***
BED	0.206804	0.0142753	14.4869	<0.00001	***
BATH	0.116549	0.031998	3.6424	0.00028	***
CAR	-0.0121199	0.0239667	-0.5057	0.61317	
AGE	-0.00438422	0.001166	-3.7601	0.00018	***
LV9	0.088038	0.0266747	3.3004	0.00100	***
DS530	**-0.0703032**	**0.0132915**	**-5.2893**	**<0.00001**	***
DC530	**0.0162304**	**0.017493**	**0.9278**	**0.35371**	
PO530	**0.0596867**	**0.017136**	**3.4831**	**0.00052**	***
DC	-0.209964	0.091346	-2.2986	0.02172	**
PO	-0.0808487	0.0983785	-0.8218	0.41136	
DCBED	0.0431564	0.0185228	2.3299	0.01999	**
POBED	0.0134222	0.0185035	0.7254	0.46837	
DCBATH	-0.0118784	0.0417346	-0.2846	0.77599	
POBATH	0.00733315	0.0439028	0.1670	0.86738	
DCCAR	0.00877748	0.0291918	0.3007	0.76371	
POCAR	0.0327262	0.0285913	1.1446	0.25262	
DCAGE	0.000188704	0.00152234	0.1240	0.90137	
POAGE	-0.000123585	0.00158928	-0.0778	0.93803	
DCLV9	-0.0436304	0.0372624	-1.1709	0.24190	
POLV9	-0.105625	0.0375175	-2.8153	0.00496	***

*** significant at 1%; ** significant at 5%; * significant at 10%

R^2	0.748933	Adjusted R^2	0.744301
F(20, 1084)	161.6786	P-value(F)	4.4e-30801
Observations	1,105		

Table 22: Macquarie Park composite distance

With data restricted to the Macquarie Park area it is pertinent to outline some aspects of lifestyle preferences that are characteristic of the area. First, Table 22 shows an extra bedroom in Macquarie Park costs an additional 20.7% *BC* of the average unit price, which is considerably higher than both Epping (13.3%) and Chatswood (16.5%) (see Tables 12 and 16), and may reflect a higher demand for student accommodation in the Macquarie Park area. Second, there is a notable absence of change in preferences for structural features across the study period apart from higher level residences, which by *PO* no longer commands a premium. In regard to proximity to rail access there has been a noticeable shift in the relative value of units closer to the new train station in the period *PO* compared with the period before the station existed. By *PO* the property premium of the more aesthetically pleasing outer zone declined to just 1.1% from 7.0% in the period *BC*.

5.4 Impact of independent variables across locations

The objective of this study is to examine new rail investment impact on property values between locations. This may be observed by examining two sets of variables measuring spatial relationships. The first set of variables concerns the study's primary focus: the relationship between the locality variables (*IMPCT* and *CNTRL*). The second set reflects the changes in distance variables (*DS530* and *DS1000*) within the impact area. The following section compares the results for each set of variables across locations.

5.4.1 Cross-location change in impact and control variables

In this study, the effect of new rail accessibility is estimated by examining the changes in property values occurring in *IMPCT* compared with *CNTRL* from periods *BC* to *PO*. The results indicate the proximity premiums increased by 7.9% at Epping, 5.0% at Chatswood, and 15.3% at Macquarie Park, (see Tables 12, 16 and 21). These findings confirm the first hypothesis:

Property prices nearby rail stations increase if those stations benefit from new or improved accessibility due to new rail investment.

The extent to which new rail accessibility impacts property prices is expected to differ according to the type of benefit received. This study shows the benefit of an entirely new rail station at Macquarie Park is substantially greater than the benefit encountered at both Epping and Chatswood, where the utility of existing rail stations is enhanced by the addition of a new service (see Tables 12, 16 and 21). This confirms the second hypothesis:

With the introduction of a new rail line, the change in the property premium derived from new rail accessibility will generally exceed the premium derived from augmented rail accessibility.

The primary aim of this study is to determine the role of *place,* as the surrounding location associated with a rail station, in modifying the impact of new rail investment on property values. To achieve this, the study estimated the difference in the perceived value of additional rail accessibility at a *town centre* (Epping) compared with a *major centre* (Chatswood). Analysis in earlier sections of this chapter show the percentage change in property premiums resulting from the new rail link is larger in Epping than Chatswood (summarised in Table 23).

Classification	**Study reference**	**Impact of augmented rail service**
Town Centre	Epping	7.9%
Major Centre	Chatswood	5.0%

Table 23: Summary of rail impact results for Epping and Chatswood

Table 23 confirms the value of new rail investment is relatively larger in a smaller centre, which supports the third hypothesis:

Ceteris Paribus, the additional premium paid for residential properties located close to rail stations that receive new rail infrastructure will be relatively lower in centres with greater size and variety of economic activity and community facilities, compared to those with fewer such attributes.

5.4.2 Cross-location change in the distance variables

This study also provided the opportunity to compare cross-locational changes in distance variables *DS530* and *DS1000.* At a glance, Table 24 reveals Chatswood exerts a higher proximity premium for residences closer to the train station, compared with those further away in the impact area (8.8%, at the 1% level), while there is no significant difference between zones in Epping. During the period covered by the three phases of the rail project the relative proximity premium between the two zones had not changed significantly at either Chatswood or Epping.

	DS530 and changes between project phases: *DV = Ln(APRICE)*					
	DS530 (BC base)		DC530 (change)		PO530 (change)	
Epping/control	0.01622 (0.01496)		0.02759 (0.01887)		0.00710 (0.02023)	
Chatswood/control	0.08888 (0.02374)	***	0.01388 (0.02852)		0.01511 (0.02842)	
Macquarie Park/control	-0.07030 (0.01329)	***	0.01623 (0.01749)		0.05969 (0.01714)	***

Standard errors in parentheses. *** significant at 1%; ** significant at 5%; * significant at 10%

Table 24: Cross-location distance variables

The Macquarie Park model indicates a 7.0% property premium in the outer band of the impact area during the *BC* phase. However, noticeably, there was a considerable shift towards relatively higher property values in the *DS530* zone, with the introduction of a new rail station. Estimates suggest *DS1000* experienced a 5.9% reduction in its comparative property premium by the period *PO,* representing a relative cost shift of $24,376 in favour of the *DS530* zone.

Chapter 6: Conclusion

As stated at the beginning of this paper the main purpose of this research was to estimate the impact of rail investment on property values and to demonstrate how this is moderated by the location within which the investment is made. The research question encapsulates this purpose and asks: *Does public investment in rail infrastructure affect nearby property values and how is this influenced by the locational characteristics of the impact area?* The motivation for this study is an interest in providing evidence to gauge the suitability of a uniform value capture tax as a means to fund new rail infrastructure.

The challenge was to estimate the proximity premium associated with accessibility at various rail *nodes* in a transit network where their *place* or locational setting is meaningfully different in terms of its delineated characteristics. Hence, the first task was to identify appropriate locations where possible proximity premiums derived from rail accessibility could be isolated from premiums generated by other locational attributes; the second was to estimate if rail investment, at these locations, had a positive effect on property values; and the final task was to compare how changes to premiums vary at different locations.

Previous empirical studies revealed two methods employed to isolate the effects of rail accessibility on property prices, both involving the hedonic pricing model. The first approach, typified in a recent study by Debrezion, Pels and Rietveld (2011), involves multiple case studies in a static or event-free environment, where proximity premiums associated with all local amenities are estimated, thereby isolating the impact of rail accessibility on residential property premiums. The second approach, adopted by Damm et al. (1980) and Grass (1992), considers a dynamic environment, where rail services change in an otherwise stable setting, enabling the direct result of new rail accessibility to emerge from the model.

The Debrezion, Pels and Rietveld's (2011) methodology has the ability to test proximity premiums associated with pre-existing rail infrastructure. However, further investigation suggests two major flaws in their approach. First, their methodology requires isolating the gravitational impact of other amenities, which may be immediately adjacent to a rail station. This is a difficult exercise and sometimes produces questionable results (Vessali 1996). Second, accounting for all conceivable local attributes that may attract a proximity premium is likely to produce a complex and unwieldy model with a high R^2 but in effect with little predictive power (Black & Machin 2011). Finally, the need for comprehensiveness in this approach may lead to inclusion of irrelevant variables, which can act to underestimate the significance of relevant variables in the model.

The Damm et al. (1980) and Grass (1992) approach overcomes the problems associated with the need to differentiate accessibility effects from other locational attributes. These authors view the value of rail investment from a dynamic perspective, which involves estimating the before and after effects of new rail infrastructure where other location attributes have not changed. The approach taken by these authors was adopted in this study.

To discover the role of *place* in promoting or restricting the impact of new rail investment on property values, it is necessary to account for other factors generally known to cause property premium variability. A review of the literature revealed that these factors include differences in property structural features, property use, neighbourhood characteristics including locational features, accessibility, general economic conditions, and methodology. The literature also showed the perceived value of rail accessibility is moderated by a number of factors. These include the type of rail service offered, whether it exists in a monocentric or polycentric urban environment, its geo-cultural location, its proximity to the station and its distance to the CBD. Therefore, the aim of the study was to eliminate all other causes of property premium variability and isolate the influence of *place* on the perceived value of rail accessibility.

Addressing the research question required a case study in which the influence of extraneous variability factors is mitigated. The case chosen for the study examined the effect of augmented rail services on property values at a *town centre* (Epping) compared with a *major centre* (Chatswood) along a new rail link in Sydney. Here, the accessibility benefit of new rail infrastructure is almost identical at both locations and the cost/benefit of CBD access is unchanged. Other known factors that lead to variances in property values were also taken into account to reveal the difference attributable to location. For example, variations of structural features were controlled in the model, effects of neighbourhood characteristics were neutralised, economic fluctuations were smoothed and the methodological approach was standardised throughout the estimation process. A secondary exercise relaxed some earlier assumptions to enable investigation of two other circumstances implied in the literature that influence value capture potential, and which are also pertinent to this study. These involve the effect of an entirely new station at Macquarie Park compared with the effect of augmented services at Epping and Chatswood; and the distance to the station of properties within the rail catchment area.

The results reveal, first the provision of rail infrastructure generates unearned income capitalised into property values, which confirms the majority experience in Mohammed et al.'s (2013) meta-analysis. Second, the perceived benefit of new rail investment is subject to the extent of the enhancement, which appears to support the proposition implied in the literature (Debrezion, Pels & Rietveld 2007). That is substantially greater property value uplift occurs with a new rail station as opposed to augmented services at an existing station. Third, the type of locality is influential in determining the value a community places on new rail infrastructure, contradicting Mohammed et al.'s (2013) assertion that location is not influential in determining the value of rail investment. In particular, as hypothesised, this study shows the benefit of new rail infrastructure is smaller in the case of an urban centre of greater economic importance than in a centre of lesser importance. Finally, no significant property value shift was encountered within rail catchment areas that experienced augmented services. However, the more substantial influence of a new rail station at Macquarie Park had an overall more positive influence on properties closer to the train station. This fits with most of the literature reviewed in this paper (Bowes & Ihlanfeldt 2001; Chen, Rufolo & Dueker 1998; Debrezion, Pels & Rietveld 2007).

Overall, this research demonstrates that the effects of new rail infrastructure are positive and capitalised into land values, although the benefits are not uniformly distributed. This lends weight to the argument supporting a value capture tax to exact the increased property value derived from improved accessibility due to new rail infrastructure. However, the results suggest the implementation of a uniform taxation policy is likely to have a disproportionately greater impact in three instances. First, communities with greater existing public amenities will forfeit relatively more of the incremental property value gain, due to rail investment, than communities less endowed. Second, communities that receive augmented rail services will bear relatively greater cost compared with those that receive an entirely new rail facility. Finally, in regard to a new rail station, those residents in the outer zone of the rail catchment area will pay relatively more of the improved property value than those closer to the station.

While the concept of value capture as a source of funding for new rail infrastructure has obvious appeal there are important considerations with regard to equitable implementation. The results show there is considerable capacity to access unearned benefits from rail investment to finance new rail infrastructure, although the mechanism to achieve this needs to be sensitive to locational differences and other matters concerning the extent of rail infrastructure delivered.

6.1 Practical and theoretical contribution of the study

This research study contributes to the body of knowledge concerning the relationship between property value and new rail infrastructure. For the theoretician, it demonstrates how new rail accessibility influences property premiums within their locational context, thus explaining some of the differences in results found in previous research.

The findings will also interest a variety of practitioners including policymakers, property investors, town planners, demographers and marketers. For policymakers this study clarifies the potential for value capture in the context of new rail investment. 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, with the view to optimising product offerings. For town planners, the study provides greater understanding of new rail infrastructure value in different locational contexts. Demographers benefit from understanding the effects of new rail infrastructure on property premiums, which has implications for sorting. For example, high proximity premiums are often a precursor to displacement, gentrification and lifestyle changes that accompany these transformations (Kahn 2007; Voith 1991). Finally, identifying the magnitude of locational premiums enables marketers to better predict demographic changes and the consequences for consumer behaviour.

6.2 Limitations of the study

The study possesses limitations relating to the extent of locational comparisons, representation of location in the model, extent of applicability, transaction price used in standardisation and selection of independent variables. These issues are addressed in the following discussion.

First, the study includes a limited sample aimed at testing two types of locations, which appear consecutively in the table of Sydney metropolitan centre classifications. However, extrapolating the findings across all location types suggests a negatively correlated relationship between the economic importance of a centre and the perceived value of rail infrastructure, if all other variability factors are held constant. Hence, the natural corollary of this study suggests the relative impact of new rail investment on property values at a *regional*, compared with a *neighbourhood centre*, would provide a greater difference than that indicated by the comparison of a *town* and *major* centre. A comprehensive sample covering all classifications would confirm this relationship.

Second, the results of the study are applicable to polycentric urban environments and unlikely to be repeated in monocentric situations. This effectively limits the value of the study to cities with urban subcentres of strategic economic importance. Nevertheless, the polycentric urban paradigm is well represented in Australia and North America. There is also growing emphasis worldwide towards efficient urban expansion through intra-city decentralisation and geographical specialisation of industry, suggesting increasing relevance for this type of study internationally.

Third, to standardise transaction prices, enabling dollar comparisons of changes in proximity premiums, price data used in the model were deflated by indices relating to established freestanding houses. While this is not ideal, it was necessary due to the absence of a suitable and complete price index for standardising unit transactions over time. Hence, inaccuracies may have occurred if the established house price index did not reflect unit price variations. However, nominal property value comparisons are not a significant element of this study, which is primarily concerned with relative changes.

Finally, not all dependent and explanatory variables were included in the regression models. This satisfied the strategic aim to simplify the models while maintaining a reasonable level of predictive power. In terms of dependent variables, only unit transactions were included in the study, which may provide different results from freestanding housing and commercial properties. With regard to explanatory variables, some particular characteristics that theoretically affect local property values were excluded from the data, due to a lack of availability. For example, the orientation of a property may affect its price. In Sydney, home seekers prefer unit residences with living areas facing towards north. In addition, unit prices may be affected by the developers' reputation. However, these factors are absent from most empirical studies of this nature, again due to a lack of available data.

6.3 Avenues for future research

This study would be considerably enhanced by expanding the scope of the research to enable inclusion of a greater variety of locational types. This may be achieved by investigating the impact of the new North West Rail Link, which is designed to deliver eight new rail stations to expand transit facilities and support an extension of Sydney's GEC.

An investigation of the North West Rail Link will also enable evaluation of a new type of transit system. This project introduces Sydney's first exclusively metro railway, which involves driverless, single-deck carriages, capable of delivering high speeds and high-frequency services, similar to efficient rapid transit systems adopted in other major urban centres internationally. An analysis of the North West Rail Link will reveal the perceived value that different communities place on the introduction of a metro, providing a measure of government policy success. Similarly, future research may address the impact of the proposed CBD south-east light rail project to assess the value communities place on this form of transportation.

Another extension of this research would be to investigate the implications of the relationship between proximity premiums and population sorting. While this study highlights the potential for new rail investment to deliver extraordinary unearned benefits for communities located close to rail improvements, there are also corresponding costs for new home seekers who aspire to live in these communities. Prospective residents must weigh up the potential utility gained from rail accessibility with the proximity premium associated with *place*. Valuable future research could reveal how the push/pull of property premiums associated with rail, and other local attributes, effectively alter the population dynamics of a community. In addition, useful information would emerge from investigating if lifestyle characteristics differ in centres endowed with efficient rail services and an array of local facilities, compared with other centres. For example, does this translate in terms of car ownership and more free time for health and recreational pursuits?

Finally, future research should explore the temporal aspects associated with the value of rail infrastructure, and its relationship with other locational features that also have gravitational attraction. For example, the changing importance of rail services and other community attributes may provide an indication of future urban population sorting. Most importantly, it will demonstrate the trend towards an increasing or diminishing role of rail infrastructure, and identify requirements for future investment. Clearly, understanding these trends will deliver invaluable insight for meeting community expectations and managing sustainable future urban growth.

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Appendix A: Sydney metropolitan strategic centres detailed criteria

Centre Type	Criteria
Global Sydney	**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, Statewide, 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

Centre Type	Criteria
	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.
Regional City	**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 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

Centre Type	Criteria
	services. The NSW Government has a strong interest in the success of Regional Cities as key structuring elements for Sydney.
Major centre	**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. • 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.

Centre Type	Criteria
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. **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.

Appendix B: Formulated time split variables

Additional formulated time-split variables used to construct the composite model are the product of the original *IV*s split according to the period of observation. The calculation of time-split variables is shown in the following table

Variable	**Calculation**	**Variable**	**Calculation**
BCBED	BC*BED	BCLV3	BC*LV3
DCBED	DC*BED	DCLV3	DC*LV3
POBED	PO*BED	POLV3	PO*LV3
BCBATH	BC*BATH	BCLV9	BC*LV9
DCBATH	DC*BATH	DCLV9	DC*LV9
POBATH	PO*BATH	POLV9	PO*LV9
BCCAR	BC*CAR	BCLV19	BC*LV19
DCCAR	DC*CAR	DCLV19	DC*LV19
POCAR	PO*CAR	POLV19	PO*LV19
BCAGE	BC*AGE	BCLV20P	BC*LV20PL
DCAGE	DC*AGE	DCLV20P	DC*LV20PL
POAGE	PO*AGE	POLV20P	PO*LV20PL
IMPTBC	IMPCT*BC	BC530	BC*DS530
IMPTDC	IMPCT*DC	DC530	DC*DS530
IMPTPO	IMPCT*PO	PO530	PO*DS530

Appendix C: Macquarie Park-Top Ryde

The Macquarie-Top Ryde model shows *IMPCT* variable coefficients -0.11434 for *BC* and -0.15003 *DC*, representing an improvement in the proximity premium of the impact area. However, the pattern is reversed *PO* when the coefficient falls to -0.13547.

	Macquarie Park–Top Ryde: *DV = Ln(APRICE)*								
Variable	Before construction (*BC*)			During construction (*DC*)			Post opening (*PO*)		
Constant	12.77690	(0.0868)	***	12.45070	(0.0480)	***	12.51310	(0.0892)	***
BED	0.19987	(0.0143)	***	0.23223	(0.0132)	***	0.22515	(0.0149)	***
BATH	0.10618	(0.0519)	**	0.16381	(0.0235)	***	0.16266	(0.0400)	***
CAR	0.03821	(0.0318)		0.03162	(0.0187)	*	0.03356	(0.0160)	**
AGE	-0.008579	(0.0013)	***	-0.006032	(0.0007)	***	-0.003790	(0.0013)	***
LVL9	0.03924	(0.0247)		-0.03196	(0.0277)		-0.03725	(0.0238)	
CNTRL	**-0.11434**	**(0.0154)**	***	**-0.15003**	**(0.0112)**	***	**-0.13547**	**(0.0116)**	***
R^2	0.616693			0.634565			0.620894		
Adjusted R^2	0.611319			0.630678			0.617109		
P-value (F)	2.9e-109			8.4e-120			3.9e-114		
Observations	435			571			608		

Standard errors in parentheses. *** significant at 1%; ** significant at 5%; * significant at 10%

Macquarie Park-Top Ryde independent variable coefficients

Appendix D: Brookvale descriptive statistics

Brookvale is used as an alternative control location for Top Ryde. The choice of this locality is supported by Grass's (1992) approach, which is primarily concerned with selecting economically stable locations even though several kilometres from the impact area. Descriptive statistics relating to Brookvale are shown in the following table.

	Brookvale (Control) data sample			
	Mean	Std Dev	Min	Max
BED	1.69	0.49	1	3
BATH	1.48	0.50	1	2
CAR	1.15	0.41	1	6
AGE	13.70	11.40	2	51
NPRICE	$423,915	$100,366	$170,000	$690,000
APRICE	$495,393	$90,244	$222,063	$783,047