Estimating Housing Supply Elasticities across Sydney LGAs

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Abstract

The real estate industry plays a pivotal role in the Australian economy. This has led to a debate regarding the determinants of real house price changes. This thesis uses annual data over the period 1991 to 2015 to estimate supply elasticities across metropolitan Sydney, at the local government level. Our results indicate that the average supply elasticity for all types of dwellings is inelastic, with the average estimated elasticity less than unity. Disaggregating the results between strata and non-strata properties provides more detail into the market forces driving the real house price. For instance, we find that about one-fifth of local government areas (LGAs) have estimated elasticities greater than one, implying that they exhibit elastic demand. On the other hand, the supply elasticity of non-strata properties across all 43 LGAs is inelastic. Having estimated supply elasticities, we also investigate which explanatory factors contribute to explaining the slope of the housing supply curves across the Sydney metropolitan area. We find that geographic factors, development approval time and population density all play significant roles in determining the supply elasticities.

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Chapter 1 Introduction

1.1 Background

Housing is essential for each human being. Residential housing plays a pivotal role, as it provides shelter, well-being and financial security (Department of Planning & Environment, 2017). From 1970 to 2003, real house prices in Australia increased at an annual rate of 3 percent (Abelson Joyeux, Milunovich and Chung, 2005); between 2003 and 2015, the weighted average house prices rose by 77 percent (ABS, 2015). As a result of the booming of housing prices, residential housing has become the largest asset held by Australians, with a net worth of 6.8 trillion Australian dollars (Michael, 2018). The importance of the housing market has been elevated to new heights due to three reasons. First, for the individual, changes in house prices lead to changes in aggregate wealth, which eventually affect aggregate consumption (Serguei, 2007). Second, for the economy, housing prices momentum directly impacts the developing side of the housing market, thereby affecting economic growth (Serguei, 2007). Finally, for the country, fluctuations in house prices influence both the supply and demand side of the housing market; for many countries, including Australia, governments scrutinize this issue as the combination of economic, regulatory and geographic (Otto, 2015).

The mounting demand and buoyant house prices have attracted researchers' attention towards housing supply constraints as the main reason for unaffordable residential properties in metropolitan Sydney. Maclennan and Malpezzi (2001) emphasized the importance of supply-side analysis for the housing market: 'Most housing models, and most policy analysis, hinge on explicit or implicit estimates of the price elasticity of supply of housing: does the market respond to demand-side shocks with more supply or higher prices?' (Malpezzi and Maclennan, 2001). However, as Serguei (2007) identified, there remain some analytical difficulties due to the absence of quality data, notably at the local government level. The inconsistency of microeconomic data and the lack of geographical data have made it difficult to researchers in this area.

This thesis addresses house price and the supply elasticity of housing in metropolitan Sydney for the 43 local government areas. Housing supply elasticity plays an important role 'in mediating urban dynamics' (Glaeser, Gyourko and Saks, 2005), indicating chain reactions from population growth to cities, whether through enlarging the size of cities or enhanced labor income, which eventually created more expensive cities (Glaeser, Gyourko and Saks, 2005). By studying housing supply, it helps us to understand two of the key intermediary elements: land availability and the structure of houses. As demonstrated in Gitelman and Otto (2012), the aggregate local housing supply in metropolitan Sydney is relatively inelastic (Gitelman and Otto,2012). Inelasticity in housing supply leads to an substantial increase in house prices when the positive demand shock hits the market. Despite the demand-side shock to the housing supply, the inadequacy between land and development and government regulatory zoning are two constraints that can also cause inelasticity in local government areas (Green, Malpezzi, and Mayo, 2005).

1.2 The uniqueness of the housing market in Sydney

This thesis focused on the 43 local government areas in metropolitan Sydney for the following reasons. First, Sydney is the largest capital city in Australian in terms of the population and the economy. Based on the 2016 census report, there are 5 million residents living in the metropolitan Sydney, and there is a

1.7% growth rate; thus, metropolitan Sydney accounts for almost 78% of the total population in the state of New South Wales (Wade, 2017). The high population and high population growth in metropolitan Sydney result in a significant demand for residential dwellings. Malpezzi and Maclennan in 2001 established a stock-adjustment model for the quantity supplied and demanded by the housing market with respect to several explanatory variables; the population is one of them. (Malpezzi and Maclennan, 2001). The question of whether the housing supply satisfies increasing demand has attracted government and researchers' attention. As a result, under the strict government regulation within the metropolitan Sydney, it is reasonable to study the housing supply in Sydney.

Second, price movements in metropolitan Sydney are an interesting case to study. Since 1970, the real housing price in Australia has increased by 3 percent every year (Abelson Joyeux, Milunovich and Chung, 2005). Between mid-2012 and 2016, the housing price in Sydney significantly increased by approximately 45 percent (Hilzhey and Skoczek, 2016), which is much higher than the other capital cities in Australia. Therefore, it is an essential city to study and understand the movements in prices.

Third, the distribution of different types of dwellings in the 43 LGAs has been observed in recent years. Under Australian Standard Geography Classification (ASGC) 2006, there are 43 local governmental areas in metropolitan Sydney. Due to the allocation of population and land availability in different LGAs, the stocks of strata and nonstrata property vary greatly. It is noteworthy to find the structure of dwelling supplied in each LGA to help authorities for future development plans.

1.3 Objectives of the thesis

This thesis has three main objectives. The first objective is to provide a better understanding of the housing market in Australia. By examining annual data from 1991 to 2015, the movement of housing prices and housing stocks can be found at a local government level. In particular, this study extended the real and nominal price movement trend patterns and the two types of dwelling stock movements in metropolitan Sydney LGAs.

The second objective is to study the fundamental economic factors that determine the housing supply in metropolitan Sydney at a local government level. By including economic factors, regulatory factors and geographic factors, we estimated the supply elasticity for strata and non-strata properties in the 43 LGAs and then investigated the endogeneity between the explanatory variables.

The third objective is to contribute to research on the supply side of the Australian housing market by examining relevant explanatory factors that determine the housing supply elasticity in metropolitan Sydney at the local government level. In particular, this study aims to extend previous studies on determinants of supply elasticity that focused on variables such as geographic factors, distance to the central business district (CBD), mean development approval time and population density.

For the metropolitan Sydney housing market, this study proceeded as follows:

- Provide preliminary descriptive statistics on the housing market among the metropolitan Sydney LGAs.
- Investigate housing supply elasticity for strata and non-strata properties across the 43 LGAs.
- Analyze the determinants of housing supply elasticity of strata and non-strata properties.

1.4 Contribution of the study

This thesis makes several contributions to the existing literature. First, the thesis contributes to the current supply-side studies in the Australia housing market. While the importance of the housing market is recognized by the researchers in Australia, the delving on this field is still behind countries such as the United States and the United Kingdom (Serguei, 2007), especially from the supply-side analysis (Richard, Green et al., 2005). There is a growing number of studies on housing supply elasticity; however, most of these studies focused on the U.S. housing market. This paper, based on the local government level focused on the 43 LGAs in metropolitan Sydney, extended the research in this field in Australia.

Second, this thesis estimates supply elasticity with a more comprehensive dataset, which is an extension of previous studies. As mentioned in section 1.2, the housing price between 2012 and 2015 has increased significantly in metropolitan Sydney, and previous studies have covered up to 2012. By including this period in our dataset, the long-run supply elasticity between 1991 and 2015 could be estimated.

Third, this thesis applied new factors to investigate the linkages between supply elasticity and the explanatory factors. A number of new factors, such as the crime rate, weekly rental and percentage of students enrolled in private school, have been added in this study. These factors have yet to be studied; thus, the current thesis will provide more updated and comprehensive results.

1.5 A preview of the thesis

This thesis has 6 chapters in total, including this introduction.

Chapter 2 is a literature review. The papers reviewed herein have examined supply elasticity with respect to different explanatory variables. The chronological development of the research could be established as below. Bourassa and Hendershott (1995) focused on real house price movements in the Australian capital city between 1979 and 1993. Malpezzi and Mayo (1997) investigated the effects of government regulations on housing supply in the Malaysia market. Green, Malpezzi and Mayo (2005) estimated the supply elasticities for 45 U.S. metropolitan areas based on a model developed by Capozza and Helsley (1989) and Mayer and Somerville (2000). Otto and Gitelman (2012) estimated the supply elasticity for the Sydney housing market and extended their study with Liu in 2017. These studies provided a list of variables for us to consider in chapter 2; we discuss three main types of factors, namely, regulatory, geographic and economic factors.

Chapter 3 discusses the housing market in Australia. Based on the data for the normal house price index, the consumer price index and the real house price index for strata, non-strata and all properties in metropolitan Sydney between 1991 and 2015. An overview of the housing market in metropolitan Sydney will be presented at a local government level, and then, cross comparisons between the three rings in Sydney will be provided.

Chapter 4 provides a preliminary data analysis. It discussed the three main factors mentioned in the literature review and then presented detailed sources of data for each variable. Data for economic factors include income, dwelling quantities, dwelling prices, interest rates and demographic factors. Data for geographic and regulatory factors include land availability, distance to the CBD and development approval.

Chapter 5 presents the modeling for housing supply elasticity in Sydney and discusses the model development processes. The model constructed herein can help to determine the estimations for supply elasticity of strata and non-strata dwellings in the 43 LGAs. Following the cross-section analysis on the determinants of the supply elasticity variation.

Chapter 6 presents a summary of findings and provides conclusions about the Sydney housing market, especially about the supply elasticity estimations and the determinants of the elasticities. Then, we discuss the limitations of this thesis and future directions.

Chapter 2 Literature Review

2.1 Introduction

In recent decades, the literature on the housing market in Australia has grown significantly; however, most of the studies are from a demand-side analysis. For supply-side studies, with equivalent importance, there are fewer substantial works at the local government level. This chapter will review previous literature on this issue.

2.2 Review of housing supply studies

The importance of housing supply-side studies has been recognized globally, and studies from all over the world have examined this topic. The existing literature on housing supply elasticities studies is based on three main types of factors: regulatory, geographic and economic factors.

Earlier studies on regulatory factors were mainly conducted by American researchers. Malpezzi and Mayo (1997) conducted a case study on the late 1980s' Malaysia housing market. By developing a cost-benefit model, government interventions such as regulations, taxes and subsidies have been taken into account to test whether the benefits from regulatory can outweigh the costs. Applying an analysis of the aggregate supply model, the detailed housing supply behavior can be evaluated. By demonstrating cross-country comparisons with three more countries (the U.S., Thailand and Korea), the relationship between regulatory environments and supply elasticity in houses could be identified. Although the earlier study succeeded in identifying the effects of regulatory on housing supply elasticities, they are not conclusive for not including enough explanatory variables. Green, Malpezzi, and Mayo (2005) expanded their previous study by undertaking the results from across countries to imply that it may also be true across cities in the U.S. Based on the congenital advantages in the U.S. housing market, with the significant local variation in land use and other regulatory in practice, the supply elasticity estimations on each individual metropolitan area could be established. The authors implied a model originally developed by Capozza and Helsley in 1989, which was then extended by Mayer and Somerville in 2000, to conduct a more realistic user cost model. The model built reflects important characteristics of the U.S. housing market by including explanatory variables such as the cost of capital, growth rate for the city, population of the city, house prices at some fixed point in the city, transportation cost and factor of proportionality that is increasing in density. To maintain the completeness of man-made regulations, zoning and other land use regulations should also be considered. Glaeser, Gyourko, and Saks (2005) examined the causes of increasing housing prices based on supply-side effects. Whether zoning and permitting from local authorities will affect supply elasticities across metropolitan areas. Authors established a model based on the utility function by considering factors such as living preferences (in town or in the reservation locale) for people, the population, the population density, asset value, and relative developing costs. First, they formulated an equation for total asset worth. Then, they examined the maximized developer spending based on the regulatory effects on the project (the amount of time and cash spent to influence the zoning board). Finally, they determined the total benefits or loss from development of the project. As a result, from the empirical analysis, the relationship between supply elasticity with restrictive zoning and other land use regulations could be proxied.

Several studies have focused on geographic factors in estimating housing supply elasticity. In 2010, with the help of satellite-generated data, Albert Saiz built a model that directly measures the availability of land for development to emphasize the importance of geographic factors towards the housing market in the U.S., and the housing supply elasticities can be characterized from it. Wang, Chan, and Xu (2012) used data collected from 1998 to 2009 across 35 Chinese cities to study the Chinese housing market supply elasticity with respect to the impact of land availability. Several Australian studies have found relationships between land use regulations and housing market outcomes as well. In 2007, Alan Moran found that land regulations affect productivity in new housing development to influence housing prices. Tony Richards (2009) analyzed the housing market developments in Australia by considering the land availability along with macroeconomic factors such as population, household size, weekly income and housing prices. In 2010, Steven Kennedy worked with Australian Treasury to measure housing supply and affordability. Based on the third Intergenerational Report (IGR), housing supply development could be obtained. By analyzing the housing supply and affordability, taking local land regulation into consideration, the supply elasticity could be estimated.

A number of other researchers have focused on the economic factors that affect the Australian housing market. Bodman and Crosby (2003) examined the evidence regarding bubbles in Australia. By applying data for the five largest cities, authors examined factors such as real interest rate, real rental return, income per capita, population variable, and real materials costs with respect to the housing price movements in Australia. Abelson, Joyeux, Milunovich and Chung (2005) aimed to explain the real house price movements in the Australian market from 1970 to 2003. Based on standard demand theory, housing prices could be modeled with disposable income, user cost, consumer price index and demographic factors. Then, they established a long-run equilibrium model to estimate the long-run elasticity of housing prices with respect to the relevant economic factors. Ralph McLaughlin (2011) focused on five capital cities in Australia (Adelaide, Brisbane, Melbourne, Perth and Sydney) examined the new housing supply based on the growth in governmental policies. The relationship between the changes in housing price, metropolitan growth polices, and the new housing supplies in the five targeted capital cities has indicated that housing supply is elastic to the changes in price. Within the same year, McLaughlin published another paper, which investigated the housing supply elasticity in Australia between different types of dwelling. In this paper, author extended previous researches by including one more Australian capital city Hobart with a longer panel (1983-2010). The findings suggested that in the new dwelling market, multifamily unit has a larger supply elasticity than single-family unit. Gitelman and Otto (2012) used panel data covered from 1991 to 2012 to estimate the housing supply elasticity in metropolitan Sydney. The variables they used are income per capita, real and nominal interest rate, consumer price index in Sydney, and demographic factors at a local governmental level. Glavac, McLaughlin and Sorensen (2016) examined the housing supply elasticity in Adelaide with a quarterly time interval based on the previous research from Gitelman and Otto(2012) by including new geo-economic variables. Australian Housing and Urban Research Institute (AHURI) (2017) conducted a research on housing supply in Australian market. Authors developed the analysis through three aspects. The first is modeling the drivers of housing supply. The second is determining governmental policies such as Land use and planning on housing supply. The third is the responsiveness of housing supply on the institutional settings.

As discussed above, most of the previous studies for housing supply elasticity estimations are based on foreign countries. The only formal empirical study for Australia is found in Gitelman and Otto (2012). The current thesis is an extension of their research, based on 43 LGAs in metropolitan Sydney using 25 annual observations to estimate the housing supply elasticity and the factors affecting the results.

2.3 Economic factors

In this section, we review the studies that consider the economic factors that affect the housing market. We look at the studies that utilized explanatory variables such as real income per tax payer, dwelling prices, dwelling quantities, demographic factors and other economic factors.

2.3.1 Income

Income as a measurement of household consumption power plays a pivotal role in driving house prices. In earlier Australian studies, Abelson (1994) examined the house price differences in three Australia capital cities between 1970 and 1993 (Sydney, Melbourne and Adelaide) with respect to the economic factors that affect the results. By applying an ordinary least squares (OLS) model, the author found that real income has a strong positive effect on housing prices and housing demand. In 1995, Bourassa and Hendershott focused on the movements in Australian housing prices between 1979 and 1993. Based on the annual data for six capital cities, the authors conducted an OLS analysis and found that the major growth in housing prices is caused by the increase in real income. The Arrow-Debreu model (Arrow and Debreu, 1954) suggests that under certain economic assumptions, there must be an equilibrium point where a set of prices leads to the aggregate supply equals the aggregate demand. The positive income effects on house prices and demand will eventually increase the housing supply.

2.3.2 Dwelling quantities and prices

Two of the most important factors in all housing market analyses are the dwelling quantities and the real prices. The dwelling quantities could be regarded as the amount of residential properties available for the market to supply, and the real prices could be considered the motivation for developers to develop new projects. Abelson, Joyeux, Milunovich and Chung (2005) examined the housing prices in Australia between 1970 and 2003. The role of fundamental factors was examined using a dynamic ordinary least squares (DOLS) model. Based on the results from the regression model, the housing supply is a significant explanatory variable.

Wang, Chan and Xu (2012) provided an estimation of the price elasticity of housing supply in China from 1998 to 2009. First, they embellished the stock-adjustment model established by Malpezzi and Maclennan in 2001 as the equation below:

$$Q_{dt} = \delta(K_t^* - K_{t-1})$$

$$K_t^* = \alpha_0 + \alpha_1 HP_t + \alpha_2 INC_t + \alpha_3 POP_t + \alpha_4 OwnCost_t$$

$$Q_{st} = \beta_0 + \beta_1 HP_t + \beta_2 HP_{t-1} + \beta_3 HP_{t-2} + \beta_4 ConCost_t + \beta_5 MRate$$

$$Q_{dt} = Q_{st} \tag{2.1}$$

where Q_{dt} and Q_{st} is the log value of the housing demanded and supplied in the market, K_t is log of housing stock, HP_t is the log house prices, POP_t is the log value of total residential population, $OwnCost_t$ is the owner cost of the property, $ConCost_t$ is the log value of construction cost, and $MRate$ is the mortgage interest rate. Under the long-run market equilibrium, the housing supplied equals the housing demanded. By converting equation (2.1) into a model with HP as the dependent variable, we have:

$$HP_t = \frac{\delta\alpha_0 - \beta_0}{\beta_1 - \delta\alpha_1} + \frac{\delta\alpha_2}{\beta_1 - \delta\alpha_1} INC_t + \frac{\delta\alpha_3}{\beta_1 - \delta\alpha_1} POP_t$$

$$+ \frac{\delta\alpha_4}{\beta_1 - \delta\alpha_1} OwnCost_t - \frac{\delta}{\beta_1 - \delta\alpha_1} K_{t-1}$$

$$- \frac{\beta_2}{\beta_1 - \delta\alpha_1} HP_{t-1} - \frac{\beta_3}{\beta_1 - \delta\alpha_1} HP_{t-2}$$

$$- \frac{\beta_4}{\beta_1 - \delta\alpha_1} ConCost_t - \frac{\beta_5}{\beta_1 - \delta\alpha_1} MRate_t \qquad (2.2)$$

where δ is the adjustment speed for housing, and β_1 is the price elasticity of housing supply. From equation (2.2), by incorporating a stochastic term, the authors derived a reduced-form equation:

$$HP_t = \gamma_0 + \gamma_1 INC_t + \gamma_2 POP_t + \gamma_3 OwnCost_t + \gamma_4 HP_{t-1}$$

$$+\gamma_5 HP_{t-2} + \gamma_6 ConCost_t + \gamma_7 MRate_t + \gamma_8 K_{t-1} + \varepsilon_r \qquad (2.3)$$

Thus, from equations (2.2) and (2.3), the price elasticity β_1 can be stated as:

$$\beta_1 = \delta(\frac{\alpha_2}{\gamma_1} + \alpha_1) \qquad (2.4)$$

Equations (2.3) and (2.4) indicated that explanatory variables such as dwelling quantities (the market equilibrium where $Q_{dt} = Q_{st}$= dwelling quantities) and real housing prices play a highly significant role in analyzing the housing market.

2.3.3 Interest rate

The interest rate is an important factor in analyzing the housing market. It plays a significant role in both the supply side and demand side of the market. Based on the market asset approach, interest rates exert negative influence on housing prices and residential development activities. From the demand side of the market, with an increase in interest rate, the holding cost of dwellings becomes higher, which leads to a decrease in demand resulting in lower prices. From the supply side of the market, due to the increase in interest rate, the user cost of money increased as the opportunity cost of developing residential projects increased compared to holding money if the interest rates increased.

Abelson (1994) constructed an OLS model based on the annual dataset for three major capital cities in Australia: Sydney, Melbourne and Adelaide between 1970 and 1993. By including factors such as nominal house prices, gross domestic product, interest rate (real mortgage rates and real 90-day bond rate), the real All-ordinaries index rate, demographic factor (foreign immigration into Australia) and the dummy variables for housing assistance and no negative gearing. The regression model can be presented as follows:

$$HP_{t,i} = \alpha_0 + \alpha_1 HP_{t-1,i} + \alpha_2 GDP_t + \alpha_3 Rmort_t + \alpha_4 R90bond_t + \alpha_5 All_t$$

$$+\alpha_6 Nfim_t + \alpha_7 HAS_t + \alpha_8 NNG_t + e_t \qquad (2.5)$$

From the result, the author found that the real interest rate (real 90-day bond rate) has a negative effect on house prices in the three capital cities.

Gitelman and Otto (2012) examined the housing supply elasticity for the Sydney housing market. Based on the annual dataset from 1991 to 2006, authors established a reduced-form model for house prices in the 43 LGAs in metropolitan Sydney. By considering real income, demographic factor (population in each LGA), real interest rate (Australian Government index bond rate) and nominal interest rate (10-year government bond rate), the equation for real house prices will be:

$$\ln P_{i,t} = \pi_Y \ln Y_{i,t} + \pi_P \ln Pop_{i,t} + \pi_R R_{i,t} + \pi_r r_{i,t} + \widetilde{\alpha_i} + e_{i,t} \qquad (2.6)$$

This regression model indicates that the housing prices in each Sydney LGA are negatively related to the real interest rate and have a positive relationship with the nominal interest rate. The results above indicated that when the real interest increases, the real house prices in each LGA tend to decrease as the opportunity costs of ownership of properties increase, and the nominal interest rate tend to increase the house prices.

2.3.4 Demographic factors

Demographic factors such as population and population density play an important role in analyzing the housing market. Glaeser, Gyourko and Saks (2005) considered the causes of housing prices gone up. By splitting the total population N into two locations town and a reservation locale, a function of total utility for people live in reservation locale is formulated as $U(N-D)$, N stands for the total number of population and D stands for people live in town. Therefore, the flow of utility in town equals $U(D) + a - (housing\ costs)$, a stands for the people prefer to live in town. The initial population live in town could be divided into property owners with a fraction of h, then the rest of $(1-h)$ stands for the renters, and all of the initial population in town assumed to stay for exactly L periods, after that the same amount of population will replace the original residents live there. Authors assume the amount of rental paid by renters will equal to the amount of interest paid by homeowners annually, and the market starts with $\underline{D}$ number of house units; then, the total value of the houses in town could be presented as: $\frac{u(\underline{D}) - \underline{U}(N - \underline{D}) + \hat{a}(\underline{D})}{r}$. Based on the assumptions authors made, the equation above states that there exists one point where the amount of development will be maximized by the average lifetime utility of all current population living in the town. Therefore, the results of this paper indicated that higher population density has a negative impact on future residents' utility, which eventually decreases future house value.

Glaeser, Gyourko and Saks (2005) conducted a housing supply-side study and found that housing supply elasticity plays an important role 'in mediating urban dynamics'. The population inflow in a city is correlated with the amount of housing supplied by that region. Thus, there will be an increase in the size of the city from supplying more houses, thereby increasing the local labor income and increasing house prices.

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2.4 Regulatory factors

The housing market in Australia is highly regulated. Land use regulations and development approval play significant roles in the supply side of the market. In this section, we review the previous studies that considered regulatory factors in housing market analysis.

2.4.1 Development approval

The development approval is measured by the length of processing time of the project for the local government to approval. Development approval is a key element for the firm to measure the profitability of a single project; an increase in the time it takes to gain approval leads to a significant reduction in the profit of a given project (Rachel et al., 2017). Development approval directly determines the presales and sale of the properties, which causes financial burden in the beginning of the project as well as delaying construction, completion and settlement times (Rowley, Costello et al. 2014). Moran (2007) found the longer time for one development activity, which will lead to higher costs for developers, imposes negative effects on the housing supply. Based on the framework built by Poterba (1984), who examined the housing market in the Netherlands, Hakfoort and Matysiak (1997) developed a two-stage least squares model with first-order autoregression to test variables such as real house prices P_t, construction cost indexes C_t, total construction time measured in hours for the development process H_t, share of subsidized housing construction S_t, and mortgage value CR_t with respect to the number of housing unit I_t. The equation can be formulated as:

$$I_t = \beta_0 + \beta_1 P_t + \beta_2 C_t + \beta_3 H_t + \beta_4 S_t + \beta_5 CR_t + AR(1) + \varepsilon_t \quad (2.7)$$

The authors found that the total construction time is negatively correlated with the number of housing units, which means the longer time it takes for one project, there will be less project developers willing to take. Liu and Otto (2017) examined the supply elasticities across the 43 Sydney LGAs. By using a scatterplot analysis, they found a negative relationship between the development approval time and supply elasticities in each LGA.

2.5 Geographic factors

Geographic determinants play a crucial role in analyzing housing supply. Natural constraints as exogenous variables affect the development of houses (Saiz, 2010). Zoning due to natural constraints causes additional costs, longer construction periods, and barriers to new projects (Saiz, 2010). As demonstrated in Gitelman and Otto (2012), the supply of housing at the local governmental level is inelastic for most metropolitan Sydney.

2.5.1 Land availability

Land availability is one of the most important determinants in analyzing the supply side of the housing market. The larger the amount of developable land available, the more residential property developers are able to construct. Saiz (2010) developed a conceptual framework that considered the land availability in the U.S. metropolitan areas. The size of city and housing prices all depend on the availability of land. The Alonso-Muth-Mills model (Alonso, 1964; Mills, 1967; Muth, 1969) suggests that cities with a stricter land use regulation limited the land availability will cause the housing prices to become more expensive, and the demand shocks will affect the supply elasticities negatively with a lower responsiveness between the house quantities and prices. Geographic structures, such as the slope of terrain, constrain land availability and characterize housing supply elasticity with respect to this impact. The propositions from the framework indicated that land constraints by their geography decrease the housing supply elasticity.

The results have been reinforced by Liu and Otto (2017). The authors extended the definition of undevelopable land from Saiz (2010) by characterizing geographic features divided the land into four types of categories. Undertaking a linear regression with the four types of topographic features with supply elasticities across 43 local governmental areas in metropolitan Sydney, the results indicated a negative relationship between the four factors that stands for land unavailability.

As demonstrated above, land availability plays a significant role not only in housing prices but also in the amount of dwelling supplied in the market.

2.5.2 Distance to CBD

The distance to the CBD is measured as the shortest distance between the most significant point in each local governmental area town center to the CBD. This factor is used to estimate the amount of money and time people spend on roads, which could be regarded as transportation costs. A longer distance will increase both time traveled and money spent on transportation, eventually increasing the transportation costs. Mayer and Somerville (2000) considered distance to be a factor affecting development costs that directly influence the supply of houses. The results indicated a positive relationship between distance and construction costs; the longer distance traveled by transport construction materials, the more time and money will be spent. However, impact fees reduced the amount of housing supply by developers as the costs increased.

Gitelman and Otto (2012) modeled the supply elasticity in each Sydney region between 1991 and 2006 by using a reduce form equation: $\ln H_{i,t}^{s} = \beta \ln P_{i,t} + a_i + v_{i,t}$. Their found 0.08 supply elasticity for non-strata properties in the inner ring, which is the closest region to Sydney CBD, 0.1 for the middle ring and 0.38 for the outer ring. The results indicated a positive relationship between the housing supply elasticity and the distance from the CBD because people move away from CBDs.

As discussed in previous studies, distance from the CBD could have a positive or negative effect on the housing supply; thus, it is an important factor to include in modeling the housing market.

2.6 Other Factors

In recent years, researchers observed some other factors which influence housing supply. Pope (2012) based on the evidence from crimes occurred in the United States during the 1990s, examined the relationship between the crime rate and surrounding property prices. The findings indicated that there is an inverse relation between the crime rate and property prices. Black (1997) evaluated the relationship between school quality and the value parents willing to pay for the properties around. The results suggest a 2.5% more pay on a 5% test score improvements. Saiz (2019) studied the housing market with response to the immigration shocks, particularly focused on the rental of housing market.

The findings indicated rental changes caused by immigration shock will increase housing demand which drive up the housing prices.

As discussed above in this section, all of the three factors affect the opportunity costs of developers. The higher crime rate leads to a higher fees for the developers, the better quality education and higher rental provide a higher value for the housing developers supplied.

2.7 Concluding comments

This chapter revised the past literature on the housing market not only in Australia but also in overseas countries. The significant role that the housing market plays in the economy has made studies dedicate more time into this area. As demonstrated above, regulatory, geographic and economic factors are the foundation for housing market studies. Section 2.3 focused on the economic factors that affect the housing market, while section 2.4 discussed the regulatory factors that include development approval. Section 2.5 provides a review of the geographic factors, such as the land availability, which is determined by the topographic features and the distance to CBD. Section 2.6 discussed other factors which include crime rate, percentage of students enrolled in private school and the weekly rental for different types of dwellings.

Table 2.1 Main Factors

Economic Factors	Regulatory Factors	Geographic Factors	Other Factors
1. Income 2. Dwelling Quantities 3. Dwelling Prices 4. Interest Rates (Nominal and Real) 5. Demographic Factors (Population and Population density)	1. Development Approval (Approval number and Approval time)	1. Land Availability 2. Distance to CBD	1. Crime Rate 2. Percentage of students enrolled in private school 3. Weekly Rental

Chapter 3 Housing Market at the LGA level in Sydney

3.1 Introduction

This chapter provides an overview description of the housing market development for the 43 Local Government areas, which comprise the Sydney Metropolitan area during the period 1991 to 2015, and compares the individual LGA markets. Section 3.2 presents the annual housing price movements in metropolitan Sydney as a whole to identify the significant turning points for the sector. Section 3.3 is based on the three geographic rings in metropolitan Sydney to apply a detailed comparison with dwelling price movements between them. Section 3.4 focused on the stock of different types of properties and the residential property construction activities approved by the local government as a whole from 1991 to 2015. Finally, section 3.5 presents the conclusion of this chapter.

3.2 Movement of house prices

Australian House Prices

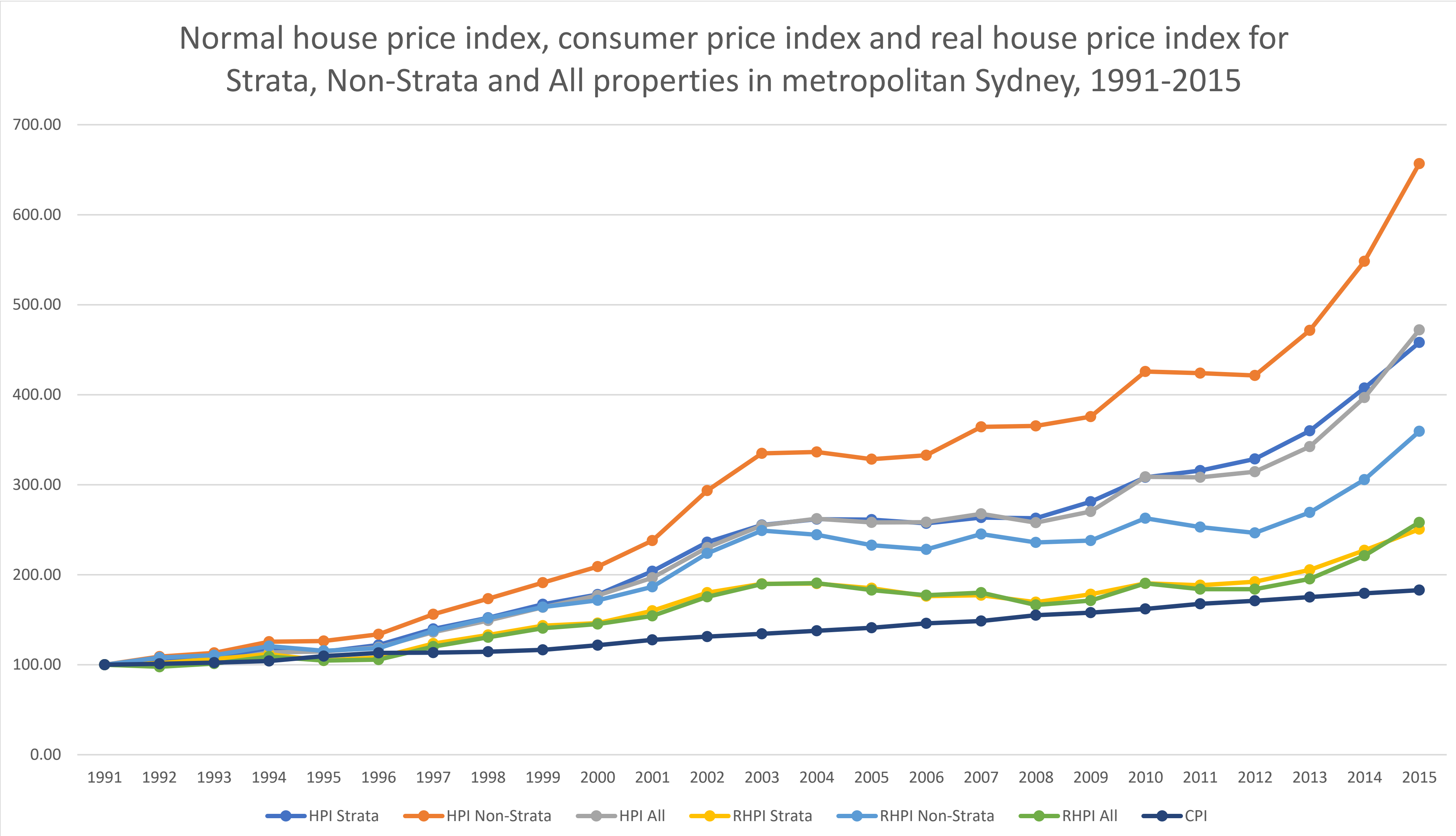
Based on past research, there are four price booms between 1970 and 2003. The most recent boom caused a dramatic price increase between 1996 and 2003 (Abelson Joyeux, Milunovich and Chung, 2005). As one of the most popular questions, whether the housing boom will bust in the future has drawn the attention of government, business and academic across Australia. Learning from history, the housing booms between 1972-1974, 1979-1981 and 1987-1989 (Abelson Joyeux, Milunovich and Chung, 2005) have increased real house prices. However, in between these periods, the growth of housing prices in the nominal term tends to slow down, followed by prolonged periods of declining housing prices in the real term (Serguei, 2007). Indeed, the latest boom between 1996 and 2003 appeared to be over, there is no sign of significant dropping in housing prices; instead, between 2003 and 2015, the weighted average house prices rose by 77 percent (ABS, 2015).

Columns 2 to 4 of table 3.1 present the annual metropolitan Sydney nominal house price index (HPI), columns 5 to 7 represent the Real House Price Index (RHPI), column 8 presents the consumer price index (CPI) between the period 1991 to 2015 for different types of dwellings. Columns 9 to 15 from the same table indicate the annual percentage changes. The nominal price data for each type of dwelling are collected from the Rent and Sales Report published by the New South Wales Government Family and Community Services (NSW Department of Family and Community Services, Report No. 120). The CPI for Sydney is collected from the Australian Bureau of Statistics (ABS; ABS Cat Nos 6401.0 (2018)). Details of the data sources and information about the data used in this chapter will be discussed in the following chapter.

Figure 3.1 shows the time series graph for the house price index, the CPI and the RHPI for the metropolitan Sydney. The nominal price could be calculated from the average of 43 individual median prices of each LGAs. The real price could be converted by using nominal prices given by Rent and Sales Report divided by the CPI for Sydney throughout the period 1991 to 2015. The results for the late 1990s and early 2000s are consistent with previous research conducted by Abelson Joyeux, Milunovich and Chung in 2005 and ABS found in 2015.

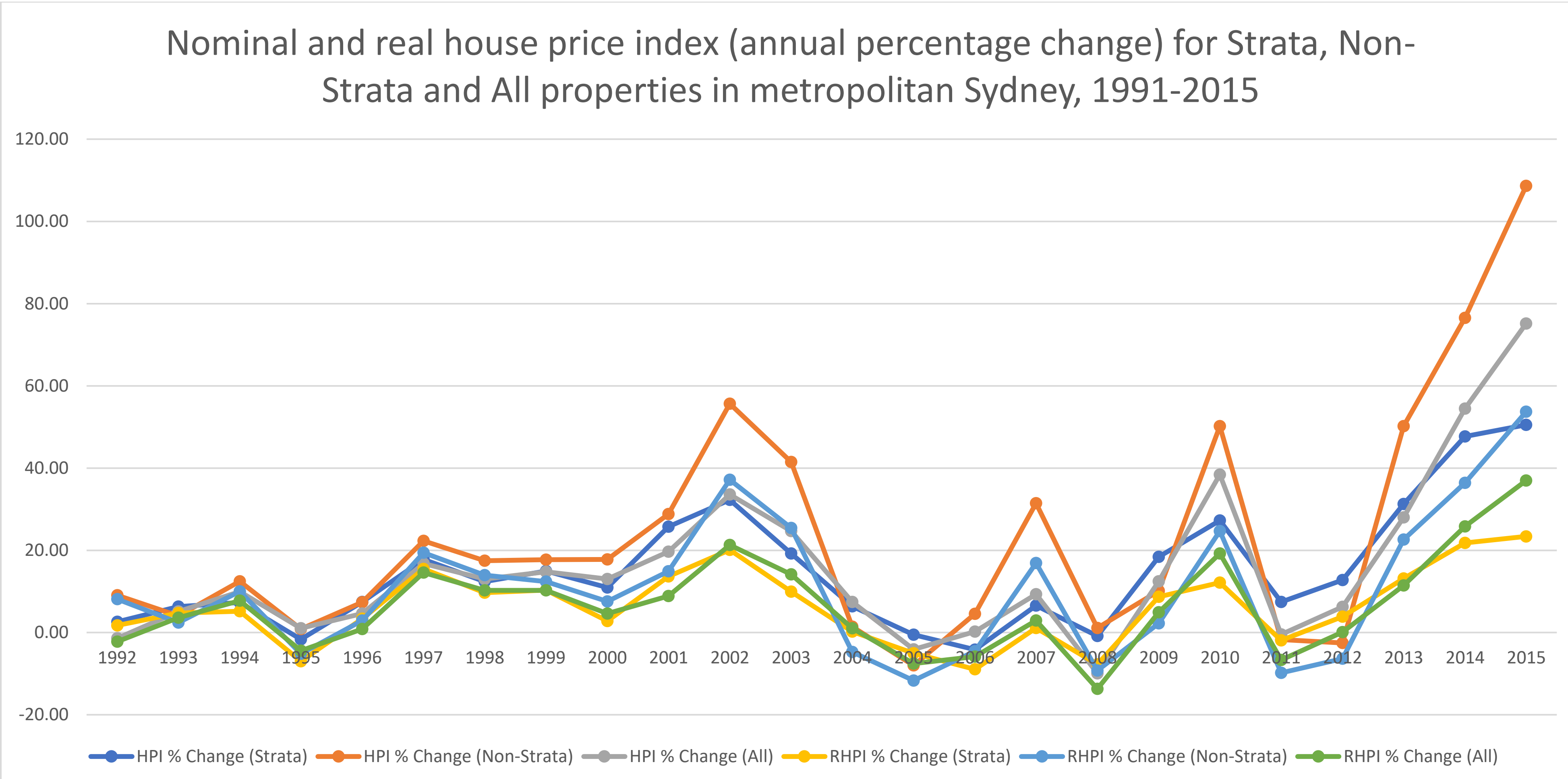
Housing prices increased significantly from 1991 to 2015, and several peaks occurred in 2003, 2010 and 2015, as shown in figure 3.1.

Figure 3.1 Normal house price index, consumer price index and real house price index for Strata, Non-strata and All properties in metropolitan Sydney, 1991-2015



The results from figure 3.1 are confirmed by figure 3.2. Figure 3.2 shows the sharply increasing peak for the same period, which shows the annual percentage change for the nominal and RHPI for strata, non-strata and all properties in metropolitan Sydney between 1991 and 2015 from columns 9 – 14 of table 3.1. Figure 3.2 indicates that nominal house prices for different dwelling types have mostly a positive fluctuation, as three of the lines are above 0. However, in the real term, there are several periods in which the fluctuation is negative. Overall, figures 3.1 and 3.2 show the co-movements of nominal and real house prices for strata, non-strata and all properties in metropolitan Sydney from 1991 to 2015.

Figure 3.2 Nominal and real house price index (annual percentage change) for Strata, Non-strata and All properties in metropolitan Sydney, 1991-2015



As shown in columns 9-14 of table 3.1, there are three periods in which both nominal and RHPI annual percentage changes exceed 10 per cent, 1997-2003, 2009-2010, 2013-2015. However, in 2000, the significant increase in nominal prices has led to only a small increase in real-term house prices, which is associated with high inflation rates. With the fluctuations in both nominal and real-term prices, the nominal house prices declined in 2005, 2008 and 2011. In contrast, real house prices declined in 1995, 2005-2006, 2008 and 2011.

Table 3.1 Annual house price index and consumer price index (1991=100) and their percentage changes, metropolitan Sydney 1991-2015

year	HPI			RHPI			CPI	% Change HPI			% Change RHPI			% Change CPI
	Strata	Non-strata	All	Strata	Non-strata	All		Strata	Non-strata	All	Strata	Non-strata	All	
1991	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NA	NA	NA	NA	NA	NA	NA
1992	102.62	109.05	98.62	101.72	108.09	97.75	100.89	2.62	9.05	-1.38	1.72	8.09	-2.25	0.89
1993	108.92	113.10	103.72	106.45	110.53	101.37	102.32	6.30	4.05	5.11	4.73	2.44	3.62	1.44
1994	116.22	125.54	113.66	111.60	120.56	109.14	104.14	7.30	12.45	9.93	5.15	10.02	7.77	1.82
1995	114.56	126.37	114.71	104.58	115.36	104.72	109.54	-1.66	0.82	1.06	-7.02	-5.20	-4.42	5.40
1996	122.01	133.72	119.33	107.93	118.29	105.56	113.04	7.45	7.35	4.62	3.35	2.92	0.84	3.50
1997	139.82	156.02	136.09	123.41	137.71	120.12	113.30	17.80	22.30	16.76	15.47	19.42	14.56	0.25
1998	152.21	173.47	149.12	133.09	151.68	130.39	114.37	12.39	17.45	13.04	9.68	13.97	10.27	1.07
1999	167.15	191.21	163.90	143.42	164.06	140.63	116.55	14.94	17.74	14.78	10.33	12.38	10.24	2.18
2000	178.08	208.99	176.91	146.23	171.61	145.27	121.78	10.93	17.79	13.01	2.81	7.55	4.64	5.23
2001	203.84	237.82	196.57	159.85	186.49	154.14	127.52	25.76	28.82	19.66	13.62	14.88	8.87	5.74
2002	236.11	293.45	230.16	179.97	223.67	175.44	131.19	32.27	55.63	33.60	20.12	37.18	21.29	3.67
2003	255.30	334.91	254.87	189.89	249.11	189.57	134.44	19.19	41.47	24.71	9.92	25.44	14.13	3.25
2004	261.63	336.31	262.30	190.13	244.40	190.61	137.61	6.33	1.40	7.43	0.23	-4.71	1.04	3.17
2005	261.11	328.29	258.20	185.09	232.71	183.03	141.07	-0.52	-8.02	-4.09	-5.04	-11.68	-7.58	3.46
2006	256.95	332.87	258.42	176.13	228.17	177.14	145.88	-4.16	4.58	0.21	-8.96	-4.54	-5.89	4.81
2007	263.53	364.34	267.72	177.26	245.07	180.08	148.67	6.58	31.47	9.30	1.12	16.89	2.94	2.79
2008	262.71	365.41	257.79	169.53	235.81	166.36	154.96	-0.82	1.07	-9.93	-7.72	-9.25	-13.72	6.29
2009	281.10	375.54	270.22	178.20	238.07	171.30	157.75	18.39	10.13	12.43	8.66	2.26	4.94	2.79
2010	308.33	425.72	308.65	190.32	262.77	190.51	162.01	27.23	50.17	38.43	12.12	24.71	19.21	4.26
2011	315.76	423.99	308.16	188.37	252.94	183.84	167.62	7.43	-1.73	-0.49	-1.94	-9.83	-6.67	5.61
2012	328.53	421.43	314.40	192.22	246.57	183.95	170.92	12.77	-2.56	6.25	3.84	-6.37	0.11	3.29
2013	359.79	471.63	342.43	205.33	269.16	195.43	175.22	31.26	50.21	28.02	13.12	22.59	11.47	4.31
2014	407.48	548.17	396.87	227.13	305.56	221.22	179.40	47.69	76.54	54.44	21.80	36.40	25.79	4.18
2015	458.00	656.83	472.04	250.52	359.28	258.20	182.82	50.52	108.66	75.17	23.39	53.72	36.98	3.42

3.3 A comparison with dwelling price movements in the three rings

In this section, we will discuss the price movements in each type of dwelling in the three rings. The 43 LGAs in metropolitan Sydney have been classified into three rings in terms of location. The three rings and respected LGAs are shown in table 3.2. From figure 3.1 and 3.2 above, it is undoubtedly the nominal and real prices of strata and non-strata properties in metropolitan Sydney have increased significantly since 1991.

Table 3.2 Grouping of LGAs

Inner Ring (11)	Middle Ring (15)	Outer Ring (17)
Ashfield	Auburn	Baulkham Hills
Botany	Bankstown	Blacktown
Lane Cove	Burwood	Blue Mountains
Leichhardt	Canterbury	Camden
Marrickville	Canada Bay	Campbelltown
Mosman	Hunters Hill	Fairfield
North Sydney	Hurstville	Gosford
Randwick	Kogarah	Hawkesbury
Sydney	Ku-ring-gai	Holroyd
Waverley	Manly	Hornsby
Woollahra	Parramatta	Liverpool
	Rockdale	Penrith
	Ryde	Pittwater
	Strathfield	Sutherland
	Willoughby	Warringah
		Wollondilly
		Wyong

To provide a more detailed comparison between the three rings, the trends for different types of dwellings have been graphed below with references to figure 3.3.1 to 3.4.3. Figures 3.3.1, 3.3.2, and 3.3.3 show the normal HPI for all three types of properties in three rings between 1991 and 2015. Figures 3.4.1 to 3.4.3 present the trends for the RHPI of all three types of properties in three rings. From the figures mentioned above, it is obvious that for strata and non-strata properties, the inner ring has the highest nominal and real prices, followed by the middle ring, and the outer ring has the lowest number in both prices. When comparing figures 3.3.1 to 3.4.3. The trends for price movements shares a common pattern, which is similar to figure 3.1, which reinforced the three major price booms mentioned in section 3.2.

Figure 3.3.1 Nominal house price index for Strata Properties in the three rings of metropolitan Sydney, 1991-2015

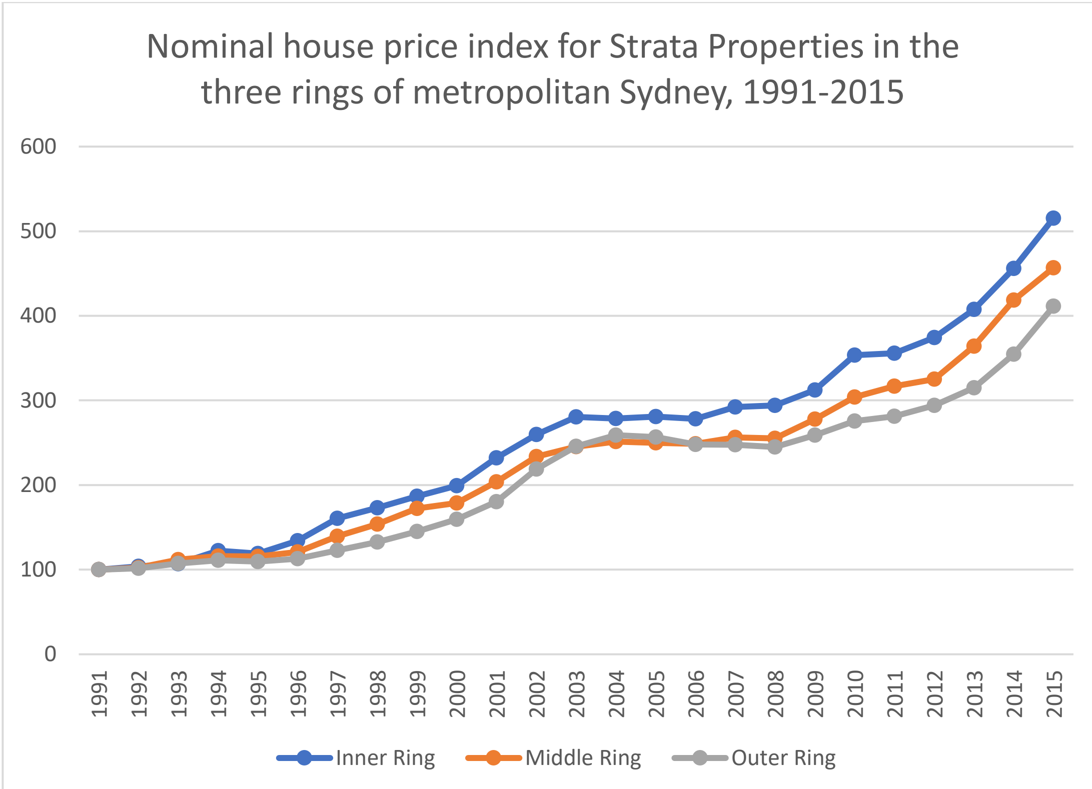


Figure 3.3.2 Nominal house price index for non-strata properties in the three rings of metropolitan Sydney, 1991-2015

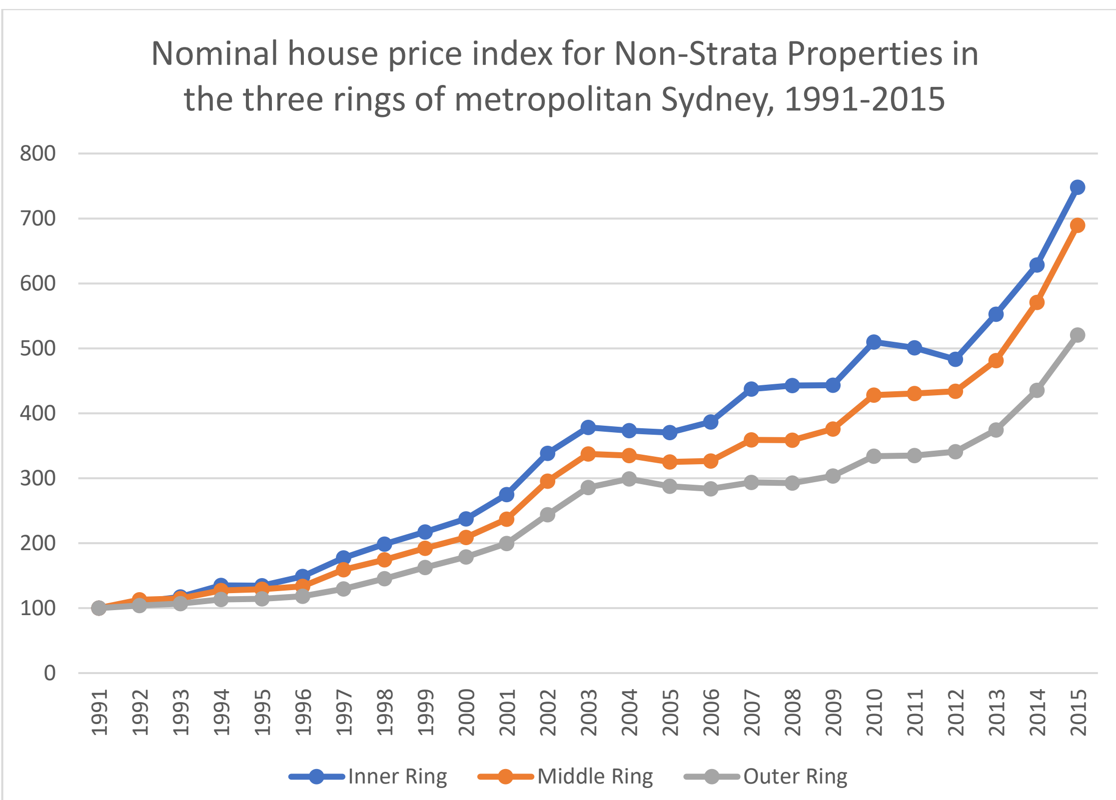


Figure 3.3.3 Nominal house price index for all properties in the three rings of metropolitan Sydney, 1991-2015

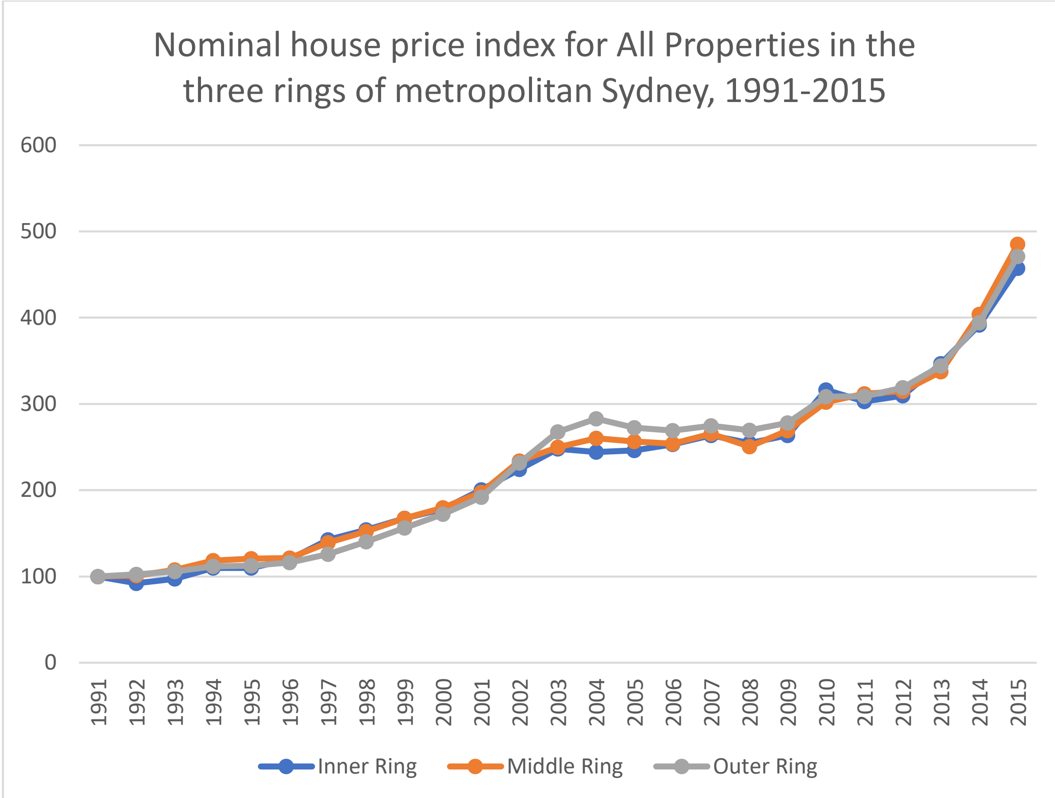


Figure 3.4.1 Real house price index for Strata Properties in the three rings of metropolitan Sydney, 1991-2015

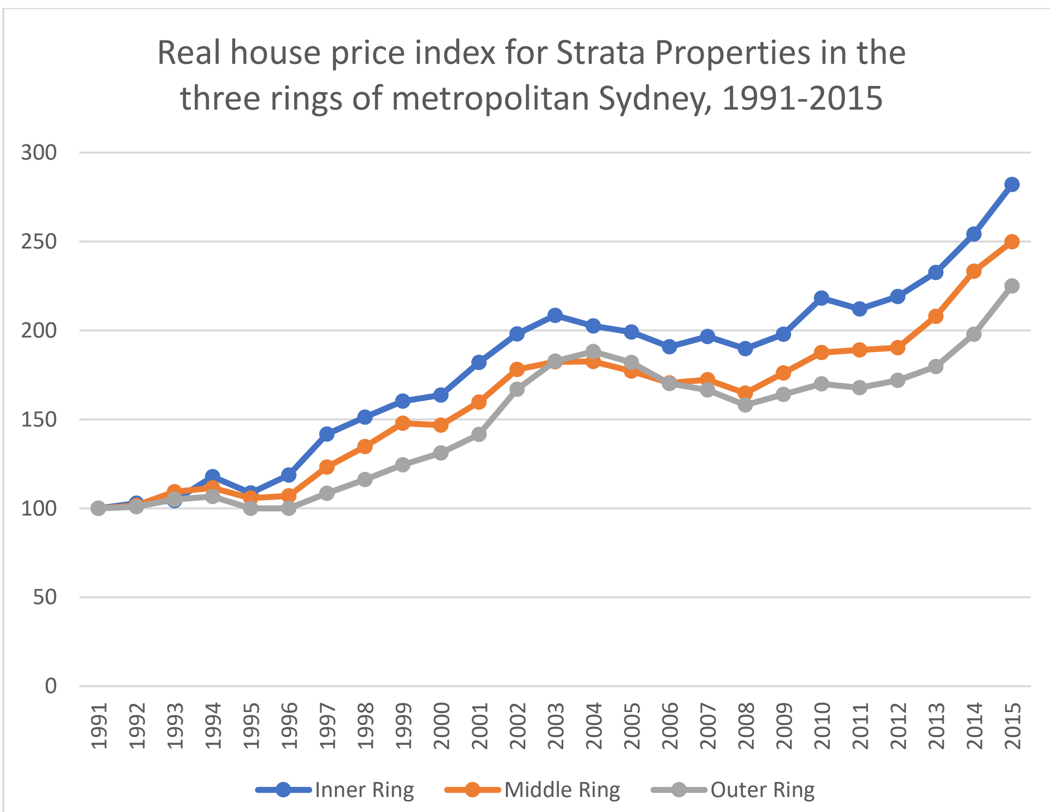


Figure 3.4.2 Real house price index for Non-strata Properties in the three rings of metropolitan Sydney, 1991-2015

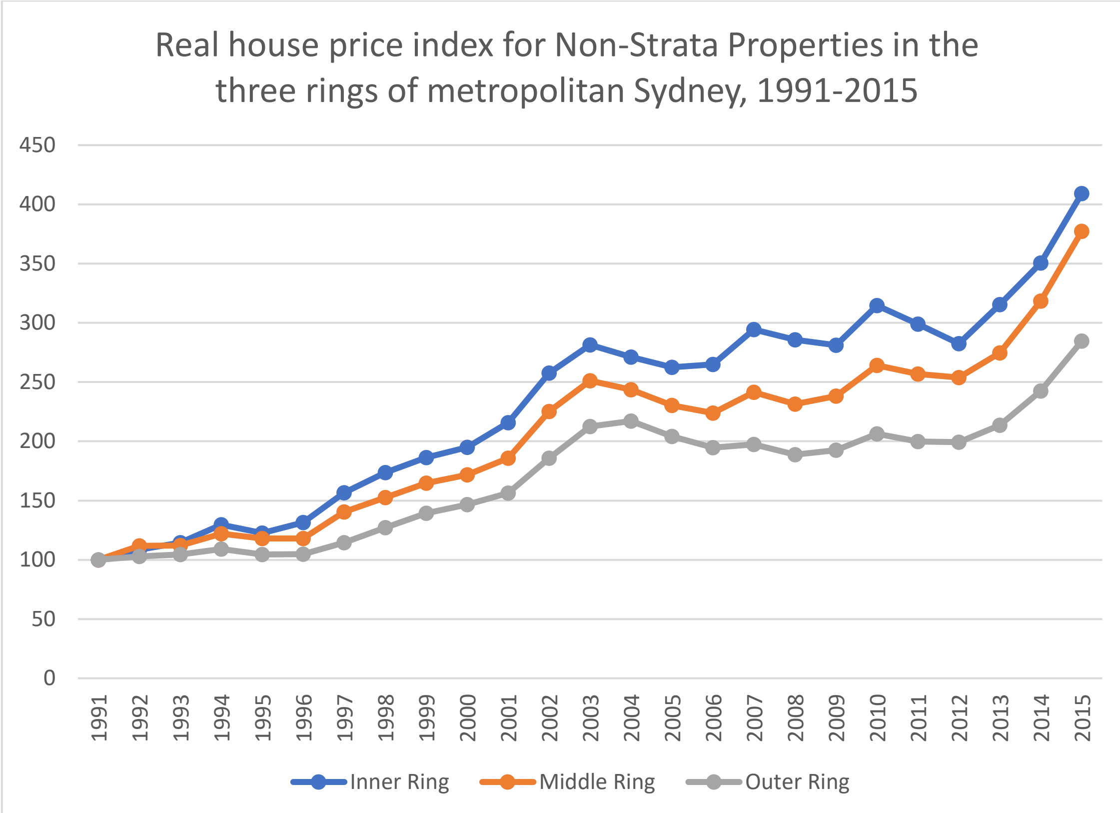


Figure 3.4.3 Real house price index for All Properties in the three rings of metropolitan Sydney, 1991-2015

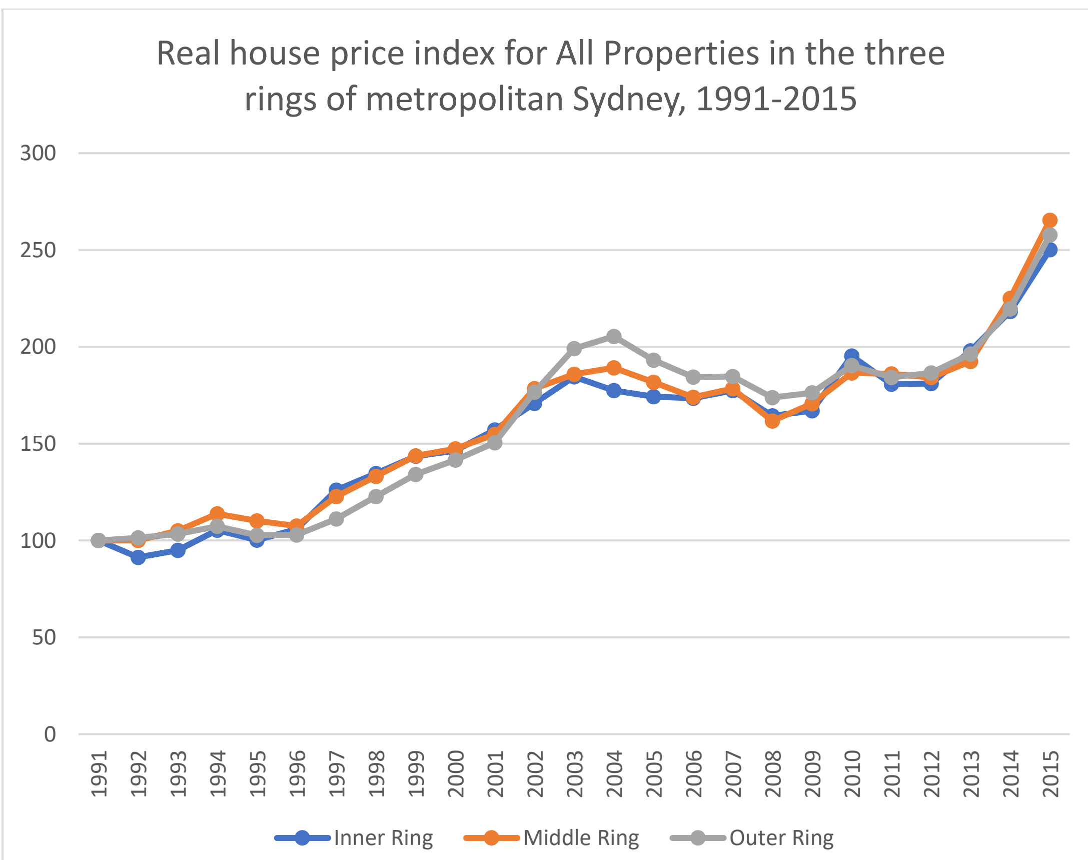


Table 3.2 Annual house price index and consumer price index (1991=100) and their percentage changes, Inner Ring metropolitan Sydney 1991-2015

year	HPI			RHPI			CPI	% Change HPI			% Change RHPI			% Change CPI
	Strata	Non-strata	All	Strata	Non-strata	All		Strata	Non-strata	All	Strata	Non-strata	All	
1991	100	100	100	100	100	100	100	NA	NA	NA	NA	NA	NA	NA
1992.00	103.78	109.61	92.15	102.87	108.65	91.34	100.89	3.78	9.61	-7.85	2.87	8.65	-8.66	0.89
1993.00	106.80	117.21	97.16	104.37	114.55	94.96	102.32	2.91	6.93	5.44	1.46	5.43	3.96	1.44
1994.00	122.60	135.09	109.74	117.73	129.73	105.38	104.14	14.80	15.26	12.95	12.80	13.25	10.98	1.82
1995.00	118.99	134.33	109.84	108.63	122.63	100.27	109.54	-2.95	-0.56	0.09	-7.73	-5.47	-4.85	5.40
1996.00	134.11	148.62	119.71	118.64	131.47	105.90	113.04	12.71	10.64	8.99	9.22	7.21	5.61	3.50
1997.00	160.47	177.41	142.71	141.64	156.59	125.96	113.30	19.65	19.37	19.21	19.39	19.10	18.94	0.25
1998.00	173.07	198.60	153.99	151.33	173.66	134.64	114.37	7.85	11.95	7.90	6.84	10.90	6.89	1.07
1999.00	186.69	217.31	167.27	160.19	186.46	143.52	116.55	7.87	9.42	8.63	5.85	7.37	6.59	2.18
2000.00	199.22	237.59	178.30	163.59	195.10	146.41	121.78	6.71	9.33	6.59	2.12	4.64	2.01	5.23
2001.00	232.05	275.00	200.32	181.97	215.65	157.09	127.52	16.48	15.74	12.35	11.24	10.53	7.30	5.74
2002.00	259.71	338.18	224.09	197.96	257.77	170.81	131.19	11.92	22.98	11.86	8.79	19.53	8.73	3.67
2003.00	280.35	378.44	248.11	208.52	281.48	184.54	134.44	7.95	11.90	10.72	5.34	9.20	8.04	3.25
2004.00	278.75	373.23	244.12	202.57	271.22	177.40	137.61	-0.57	-1.37	-1.61	-2.86	-3.64	-3.87	3.17
2005.00	280.97	370.42	245.97	199.17	262.57	174.36	141.07	0.80	-0.75	0.76	-1.68	-3.19	-1.71	3.46
2006.00	278.43	386.41	253.14	190.86	264.87	173.52	145.88	-0.90	4.32	2.92	-4.17	0.88	-0.48	4.81
2007.00	292.32	437.57	263.69	196.62	294.32	177.37	148.67	4.99	13.24	4.17	3.02	11.12	2.21	2.79
2008.00	293.96	442.57	254.62	189.70	285.61	164.32	154.96	0.56	1.14	-3.44	-3.52	-2.96	-7.36	6.29
2009.00	312.15	443.34	263.54	197.88	281.05	167.06	157.75	6.19	0.17	3.50	4.31	-1.60	1.67	2.79
2010.00	353.37	509.69	316.44	218.12	314.60	195.33	162.01	13.20	14.96	20.08	10.23	11.94	16.92	4.26
2011.00	355.59	501.11	303.05	212.14	298.95	180.79	167.62	0.63	-1.68	-4.23	-2.74	-4.98	-7.44	5.61
2012.00	374.40	483.02	309.57	219.05	282.61	181.12	170.92	5.29	-3.61	2.15	3.26	-5.47	0.18	3.29
2013.00	407.63	552.78	346.86	232.64	315.48	197.95	175.22	8.88	14.44	12.05	6.20	11.63	9.29	4.31
2014.00	455.87	628.65	391.51	254.11	350.42	218.23	179.40	11.84	13.72	12.87	9.23	11.08	10.25	4.18
2015.00	515.49	748.11	457.34	281.97	409.21	250.16	182.82	13.08	19.00	16.81	10.96	16.78	14.63	3.42

Table 3.3 Annual house price index and consumer price index (1991=100) and their percentage changes, middle ring of metropolitan Sydney 1991-2015

year	HPI			RHPI			CPI	% Change HPI			% Change RHPI			% Change CPI
	Strata	Non-strata	All	Strata	Non-strata	All		Strata	Non-strata	All	Strata	Non-strata	All	
1991	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NA	NA	NA	NA	NA	NA	NA
1992	102.49	112.77	100.90	101.59	111.78	100.02	100.89	2.49	12.77	0.90	1.59	11.78	0.02	0.89
1993	111.83	114.68	107.47	109.29	112.08	105.03	102.32	9.11	1.69	6.50	7.58	0.26	5.01	1.44
1994	116.07	127.15	118.52	111.46	122.10	113.81	104.14	3.80	10.87	10.29	1.99	8.94	8.37	1.82
1995	115.77	129.18	120.60	105.68	117.93	110.10	109.54	-0.26	1.60	1.75	-5.18	-3.41	-3.26	5.40
1996	121.00	133.28	121.53	107.04	117.90	107.51	113.04	4.52	3.17	0.77	1.28	-0.02	-2.35	3.50
1997	139.48	159.16	139.06	123.11	140.48	122.74	113.30	15.27	19.42	14.42	15.01	19.15	14.16	0.25
1998	153.96	174.64	152.35	134.62	152.70	133.21	114.37	10.38	9.73	9.56	9.35	8.70	8.53	1.07
1999	172.31	192.09	167.43	147.84	164.82	143.66	116.55	11.92	9.99	9.90	9.82	7.93	7.84	2.18
2000	178.72	209.07	179.53	146.76	171.67	147.42	121.78	3.72	8.84	7.23	-0.73	4.16	2.62	5.23
2001	203.64	237.10	197.32	159.69	185.93	154.74	127.52	13.94	13.41	9.91	8.81	8.30	4.96	5.74
2002	233.71	295.47	234.04	178.14	225.21	178.39	131.19	14.77	24.62	18.61	11.56	21.13	15.29	3.67
2003	245.18	337.51	249.85	182.36	251.04	185.84	134.44	4.91	14.23	6.76	2.37	11.47	4.18	3.25
2004	251.25	335.13	260.40	182.58	243.53	189.23	137.61	2.48	-0.71	4.22	0.12	-2.99	1.82	3.17
2005	250.01	324.96	256.39	177.22	230.35	181.74	141.07	-0.49	-3.04	-1.54	-2.94	-5.41	-3.96	3.46
2006	248.74	326.68	253.90	170.50	223.93	174.04	145.88	-0.51	0.53	-0.97	-3.79	-2.79	-4.24	4.81
2007	256.23	359.12	265.29	172.34	241.56	178.44	148.67	3.01	9.93	4.49	1.08	7.87	2.53	2.79
2008	255.15	358.47	250.71	164.66	231.33	161.79	154.96	-0.42	-0.18	-5.50	-4.46	-4.23	-9.33	6.29
2009	277.79	375.83	269.29	176.10	238.25	170.71	157.75	8.87	4.84	7.41	6.95	2.99	5.51	2.79
2010	304.02	428.07	302.29	187.65	264.23	186.59	162.01	9.44	13.90	12.25	6.56	10.90	9.30	4.26
2011	316.73	430.33	311.81	188.95	256.72	186.02	167.62	4.18	0.53	3.15	0.69	-2.84	-0.30	5.61
2012	325.08	434.12	314.75	190.20	253.99	184.16	170.92	2.63	0.88	0.94	0.66	-1.06	-1.00	3.29
2013	364.27	481.17	337.42	207.89	274.61	192.57	175.22	12.06	10.84	7.20	9.30	8.12	4.57	4.31
2014	418.38	571.07	403.75	233.21	318.32	225.05	179.40	14.85	18.68	19.66	12.18	15.92	16.87	4.18
2015	456.80	689.60	485.14	249.86	377.20	265.37	182.82	9.18	20.76	20.16	7.14	18.50	17.91	3.42

Table 3.4 Annual house price index and consumer price index (1991=100) and their percentage changes, outer ring of metropolitan Sydney 1991-2015

year	HPI			RHPI			CPI	% Change HPI			% Change RHPI			% Change CPI
	Strata	Non-strata	All	Strata	Non-strata	All		Strata	Non-strata	All	Strata	Non-strata	All	
1991	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NA	NA	NA	NA	NA	NA	NA
1992	101.81	103.92	102.38	100.91	103.00	101.48	100.89	1.81	3.92	2.38	0.91	3.00	1.48	0.89
1993	107.46	106.82	105.85	105.03	104.40	103.44	102.32	5.56	2.80	3.39	4.08	1.36	1.94	1.44
1994	111.04	113.50	111.79	106.63	108.99	107.35	104.14	3.33	6.25	5.62	1.53	4.39	3.77	1.82
1995	109.51	114.51	112.60	99.98	104.54	102.79	109.54	-1.38	0.90	0.72	-6.24	-4.08	-4.25	5.40
1996	113.01	118.50	116.33	99.97	104.82	102.91	113.04	3.19	3.48	3.31	-0.01	0.27	0.11	3.50
1997	122.90	129.58	125.93	108.48	114.37	111.15	113.30	8.75	9.35	8.26	8.51	9.11	8.02	0.25
1998	132.80	145.48	140.42	116.12	127.20	122.79	114.37	8.06	12.27	11.51	7.05	11.22	10.46	1.07
1999	145.05	162.55	156.34	124.45	139.47	134.14	116.55	9.22	11.74	11.33	7.17	9.65	9.25	2.18
2000	159.67	178.69	172.41	131.11	146.73	141.57	121.78	10.08	9.93	10.28	5.35	5.20	5.54	5.23
2001	180.45	199.41	191.91	141.51	156.38	150.49	127.52	13.02	11.60	11.31	7.93	6.57	6.30	5.74
2002	219.02	243.71	231.64	166.94	185.76	176.56	131.19	21.37	22.21	20.70	17.97	18.79	17.32	3.67
2003	245.61	285.76	267.59	182.68	212.55	199.03	134.44	12.14	17.25	15.52	9.43	14.42	12.73	3.25
2004	258.88	298.76	282.74	188.12	217.10	205.47	137.61	5.40	4.55	5.66	2.98	2.14	3.23	3.17
2005	256.86	287.87	272.61	182.08	204.06	193.24	141.07	-0.78	-3.64	-3.58	-3.21	-6.01	-5.95	3.46
2006	248.12	283.87	269.07	170.08	194.58	184.44	145.88	-3.40	-1.39	-1.30	-6.59	-4.64	-4.55	4.81
2007	247.56	293.35	274.65	166.52	197.32	184.74	148.67	-0.22	3.34	2.07	-2.09	1.41	0.16	2.79
2008	244.96	292.38	269.39	158.08	188.68	173.84	154.96	-1.05	-0.33	-1.92	-5.07	-4.38	-5.90	6.29
2009	258.79	303.56	278.02	164.05	192.44	176.25	157.75	5.64	3.82	3.21	3.78	1.99	1.38	2.79
2010	275.43	334.12	308.41	170.01	206.24	190.36	162.01	6.43	10.07	10.93	3.63	7.17	8.01	4.26
2011	281.33	334.76	308.93	167.83	199.71	184.30	167.62	2.14	0.19	0.17	-1.28	-3.17	-3.19	5.61
2012	293.99	340.85	318.83	172.01	199.43	186.54	170.92	4.50	1.82	3.21	2.49	-0.14	1.22	3.29
2013	314.75	374.24	343.95	179.63	213.58	196.29	175.22	7.06	9.80	7.88	4.43	7.10	5.23	4.31
2014	354.82	435.18	394.06	197.78	242.58	219.65	179.40	12.73	16.28	14.57	10.10	13.58	11.90	4.18
2015	411.21	520.35	471.19	224.93	284.63	257.73	182.82	15.89	19.57	19.57	13.73	17.33	17.34	3.42

Table 3.5 presents the percentage change in nominal and real dwelling prices in the three rings of metropolitan Sydney between 1991 and 2015. Like the trends for price movements, the inner ring has the leading percentage changes in the three regions. During the period, the non-strata properties in the inner ring have the highest percentage changes, with a 648.11 percent price increase in nominal term and a 309.21 percent real-term price increase. The strata properties in the outer ring have the lowest changes but still tripled the initial nominal price in 1991 and increased 1.2 times in the real term.

Table 3.5 Changes in dwelling prices in the three rings, 1991-2015

Changes in Dwelling Prices in the Three Rings, 1991-2015		Nominal Price Change (%)	Real Price Change (%)
Strata Property	Inner Ring	415.49	181.97
	Middle Ring	356.80	149.86
	Outer Ring	311.21	124.93
	Average	361.17	152.25
Non-strata Property	Inner Ring	648.11	309.21
	Middle Ring	589.60	277.20
	Outer Ring	420.35	184.63
	Average	552.69	257.01
All Property	Inner Ring	357.34	150.16
	Middle Ring	385.14	165.37
	Outer Ring	371.19	157.73
	Average	371.22	157.75

3.4 Dwelling stock and development approval

3.4.1 Dwelling stock

As section 3.2 and 3.3 discussed, the dwelling prices in Australia have increased significantly, which has resulted in housing being the largest asset held by Australians, with a net worth of 6.8 trillion Australian dollars (Michael, 2018). In this section, we will discuss the number of dwellings in each of the LGAs, as it shows the supply-side effect on housing supply elasticity.

Figure 3.5.1, 3.6.1 and 3.7.1 graphs the total number of dwellings in the 43 LGAs. In the first group, Sydney had the most significant increase and the highest number of dwellings, followed by Randwick, which has had a steady upward trend since 1991. Mosman with almost disregarded changes in total dwellings is the lowest in the inner ring. In the second group, Parramatta and Bankstown are the two leading LGAs with the highest number of stocks. It is clear that Hunter’s Hill has the lowest stock in the middle ring. For the last group, Blacktown, with the highest increase in stock, ranked first in this group, followed by the Sutherland Shire. The lowest stock occurs in Wollondilly.

Figure 3.5.1 Total Dwelling Stocks for LGAs in the Inner Ring, 1991-2015

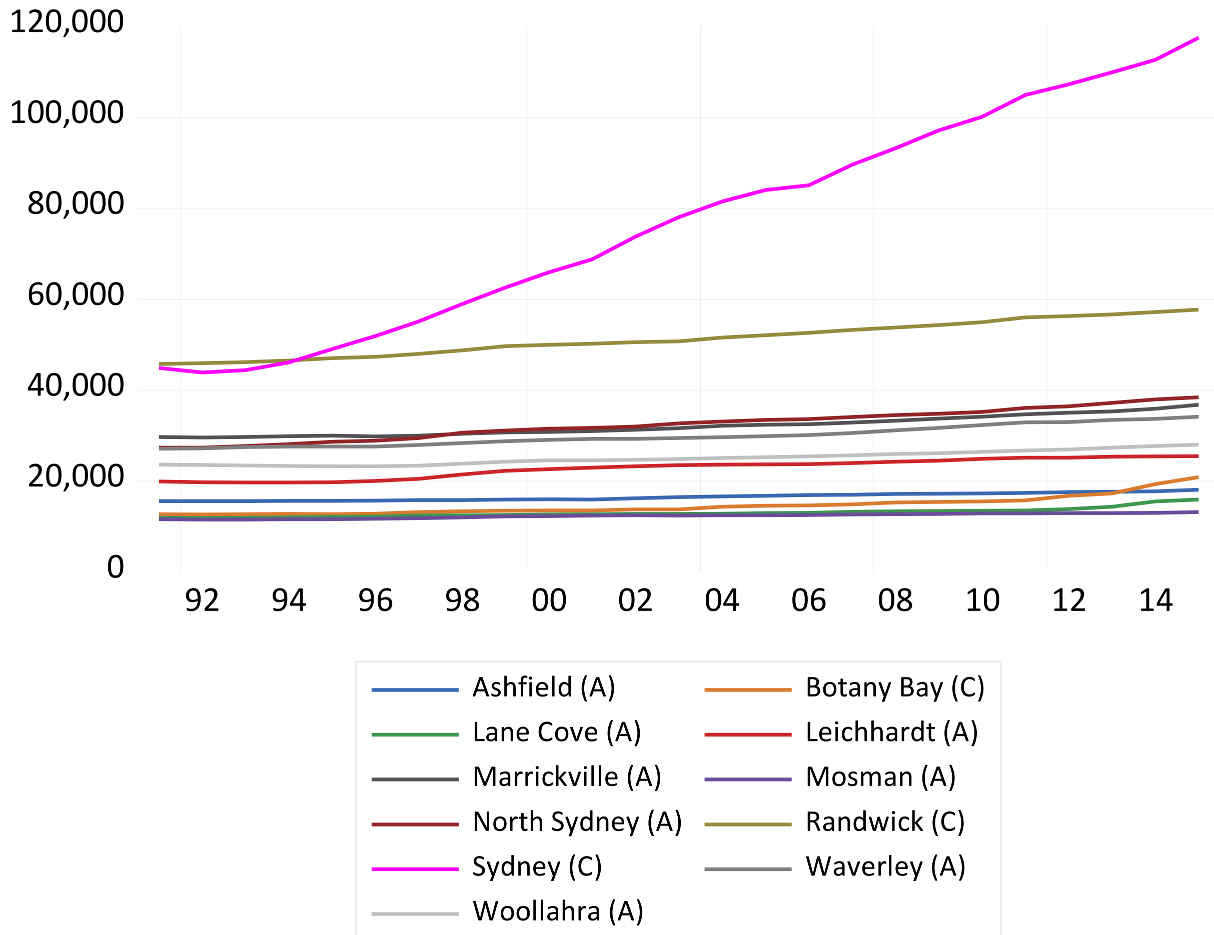


Figure 3.5.2 Strata and Non-strata Properties for LGAs in the Inner Ring, 1991-2015

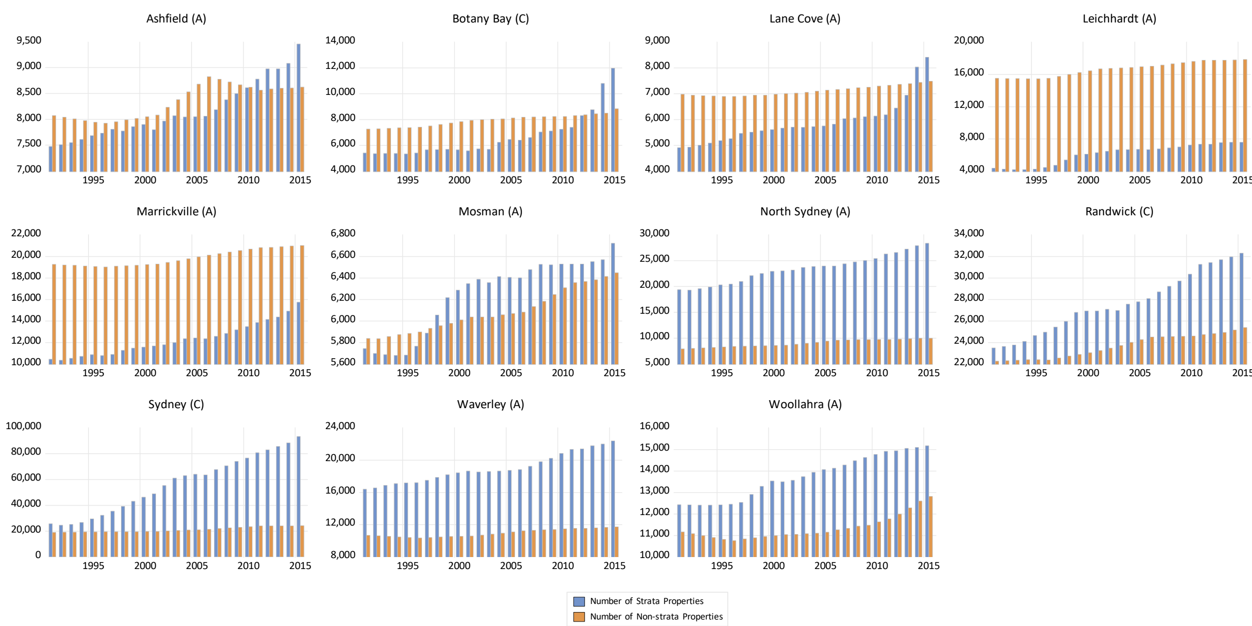


Figure 3.6.1 Total Dwelling Stocks for LGAs in the Middle Ring, 1991-2015

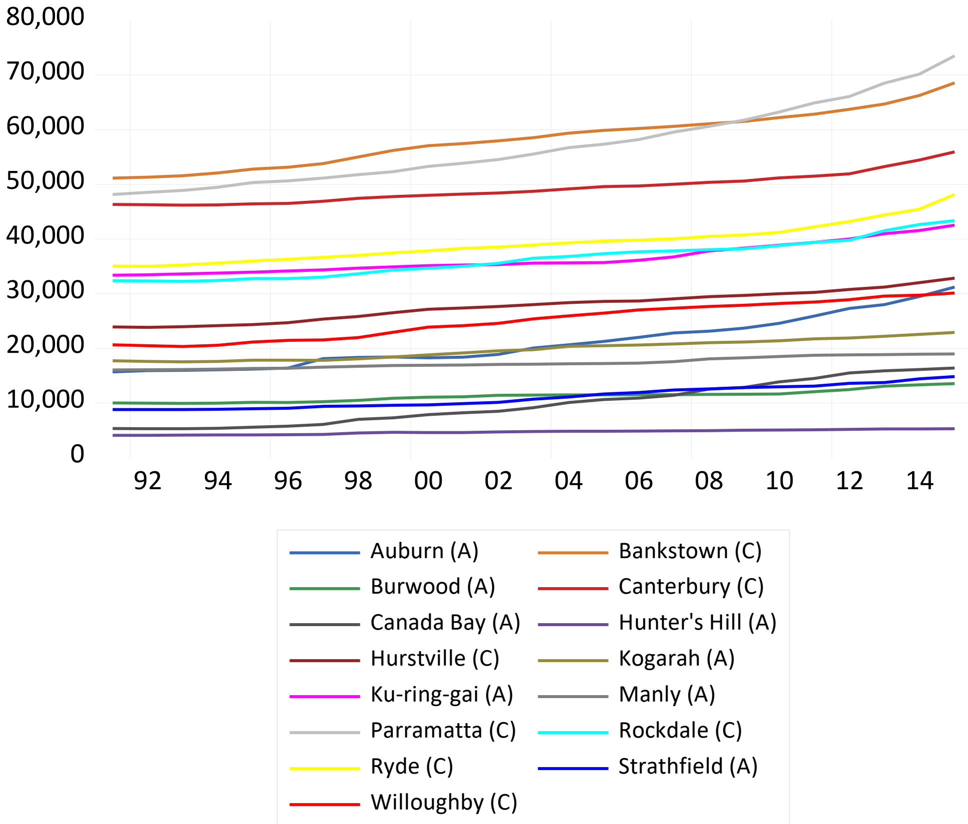


Figure 3.6.2 Strata and Non-strata Properties for LGAs in the Middle Ring, 1991-2015

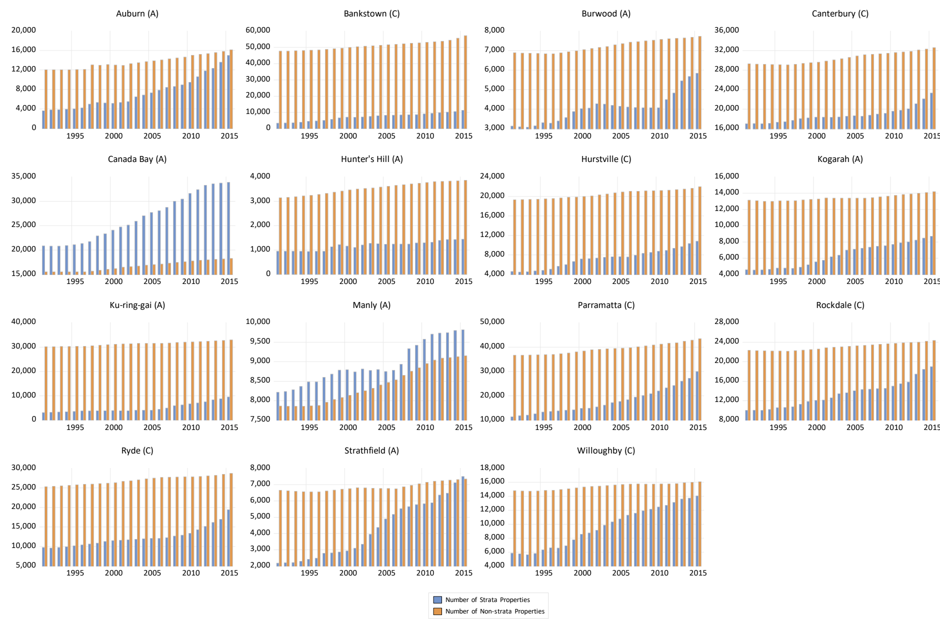


Figure 3.7.1 Total Dwelling Stocks for LGAs in the Outer Ring, 1991-2015

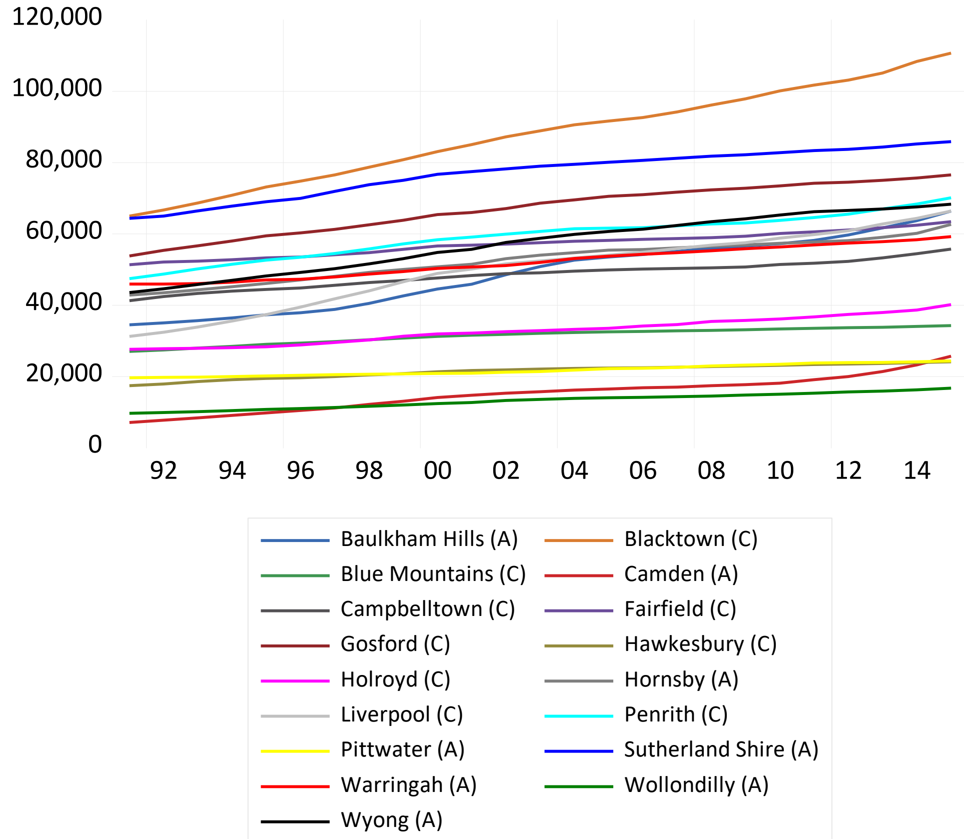
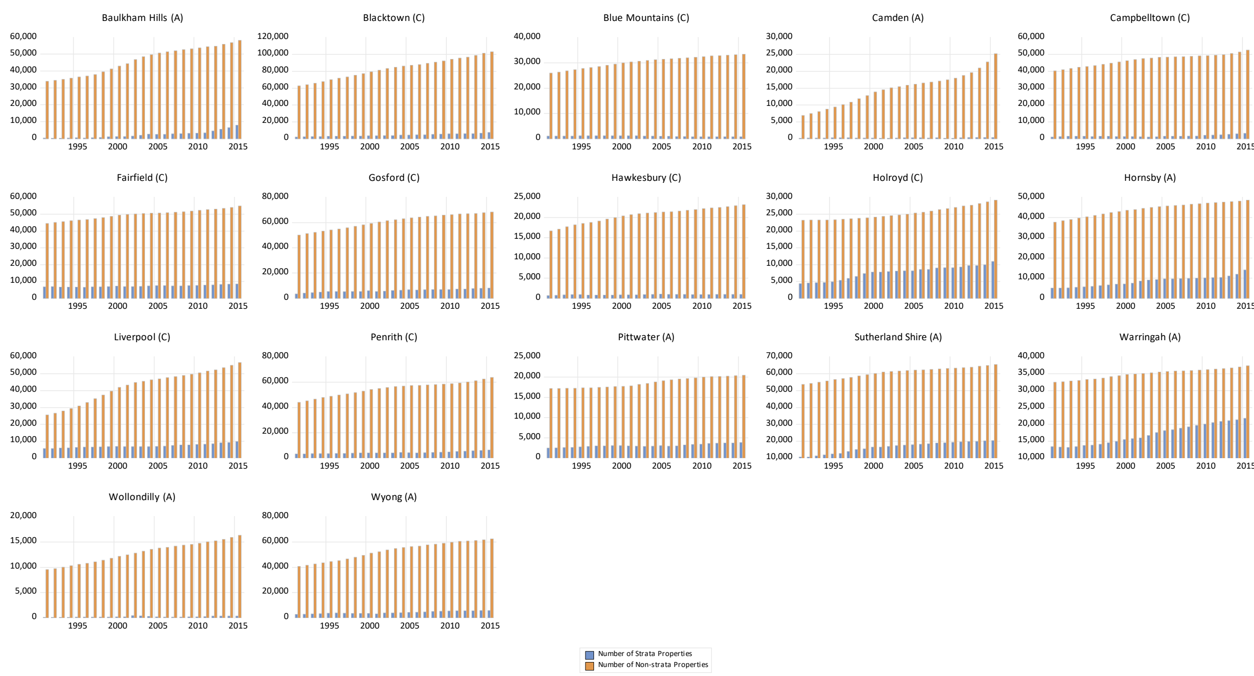


Figure 3.7.2 Strata and Non-strata Properties for LGAs in the Outer Ring, 1991-2015



In analyzing the changes for each type of dwelling in 43 LGAs, figures 3.5.2, 3.6.2 and 3.7.2 can be references. It was found that most of the LGAs have a steady increase in the stock of non-strata properties. On the other hand, the strata property stock fluctuates substantially throughout the timeframe. One major finding in the inner ring is that 9 out of 11 LGAs have a stock of strata properties that outweighs that of the non-strata properties, which occurred in only three LGAs in the middle ring, and none of the outer ring has a higher stock of strata properties than non-strata properties. The detailed information can be seen from table 3.6 below.

Table 3.6 The Distribution of Dwellings in Each Ring

Inner Ring (11)	Strata Properties outweigh Non-strata Properties	Middle Ring (15)	Strata Properties outweigh Non-strata Properties	Outer Ring (17)	Strata Properties outweigh Non-strata Properties
Ashfield	Yes	Auburn	No	Baulkham Hills	No
Botany	Yes	Bankstown	No	Blacktown	No
Lane Cove	Yes	Burwood	No	Blue Mountains	No
Leichhardt	No	Canterbury	No	Camden	No
Marrickville	No	Canada Bay	Yes	Campbelltown	No
Mosman	Yes	Hunters Hill	No	Fairfield	No
North Sydney	Yes	Hurstville	No	Gosford	No
Randwick	Yes	Kogarah	No	Hawkesbury	No
Sydney	Yes	Ku-ring-gai	No	Holroyd	No
Waverley	Yes	Manly	Yes	Hornsby	No
Woollahra	Yes	Parramatta	No	Liverpool	No
		Rockdale	No	Penrith	No
		Ryde	No	Pittwater	No
		Strathfield	Yes	Sutherland	No
		Willoughby	No	Warringah	No
				Wollondilly	No
				Wyong	No

3.4.2 Dwelling approval in metropolitan Sydney

Development approval by each LGA measures the potential amount of new dwelling available for supply in the market. Figure 3.8.2 and 3.9.2 show the amount of strata and non-strata properties approved in each of the LGAs in the inner ring and middle ring. From the two figures, it is clear that all of the LGAs have a higher approval number for the strata properties due to the increasing population. From figure 3.10.2, 12 out of 17 LGAs have a higher approval number for the non-strata properties, which indicates that when land availability is higher and population density is lower, the more non-strata properties tend to be developed. If we look at figures 3.8.1, 3.9.1 and 3.10.1, similar results could be observed, as the LGAs with the highest number of dwelling approved always result in a high number of dwelling stocks, as discussed in the previous section.

Figure 3.8.1 Total Dwelling Approval for LGAs in the Inner Ring, 1991-2015

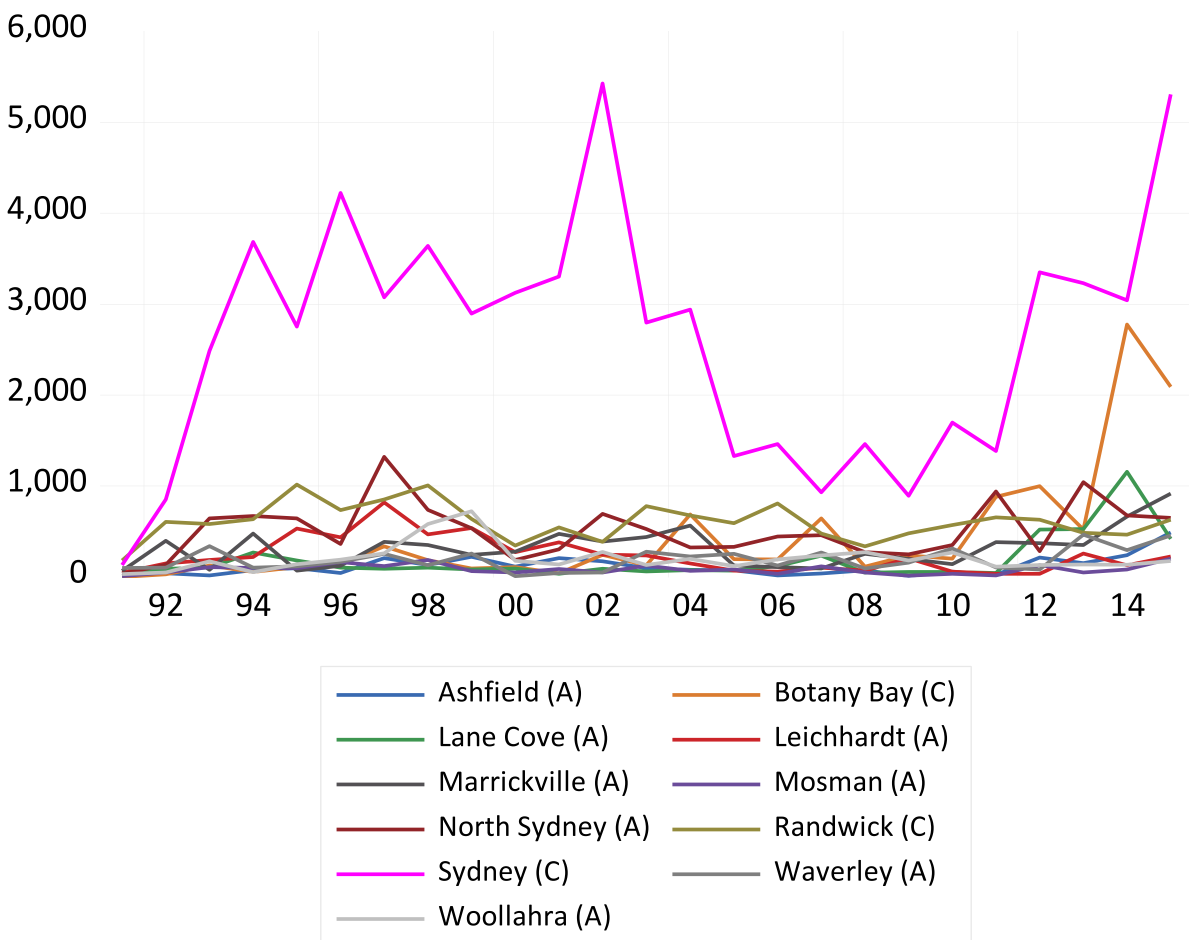


Figure 3.8.2 Strata and Non-strata Properties Approval for LGAs in the Inner Ring, 1991-2015

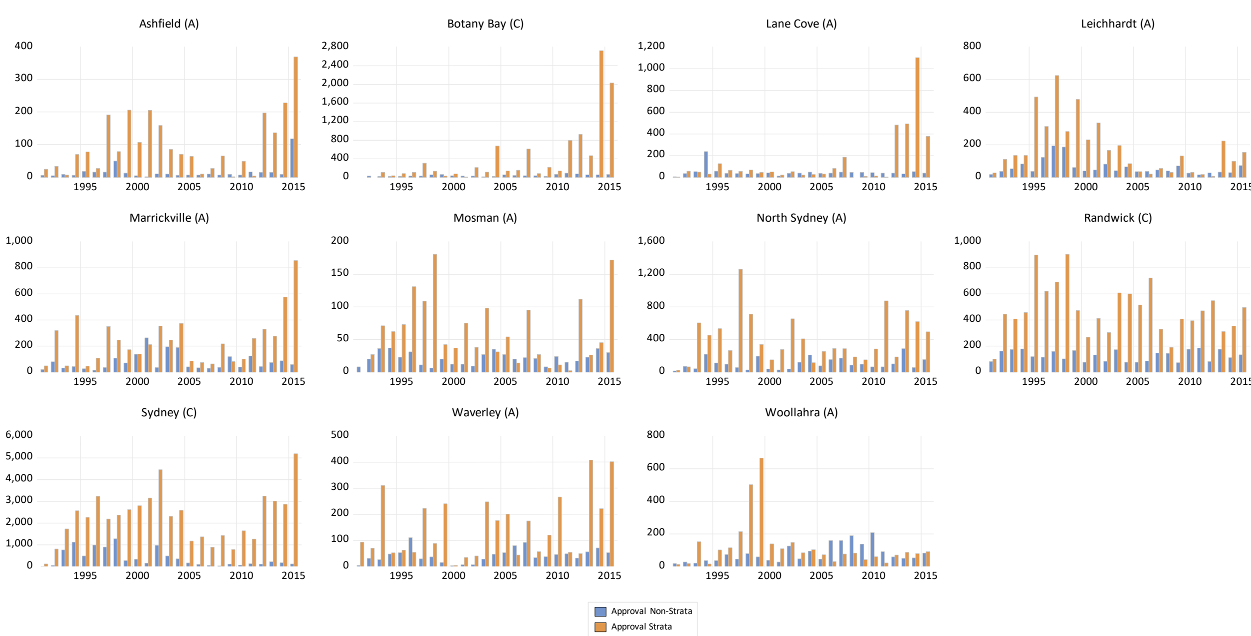


Figure 3.9.1 Total Dwelling Approval for LGAs in the Middle Ring, 1991-2015

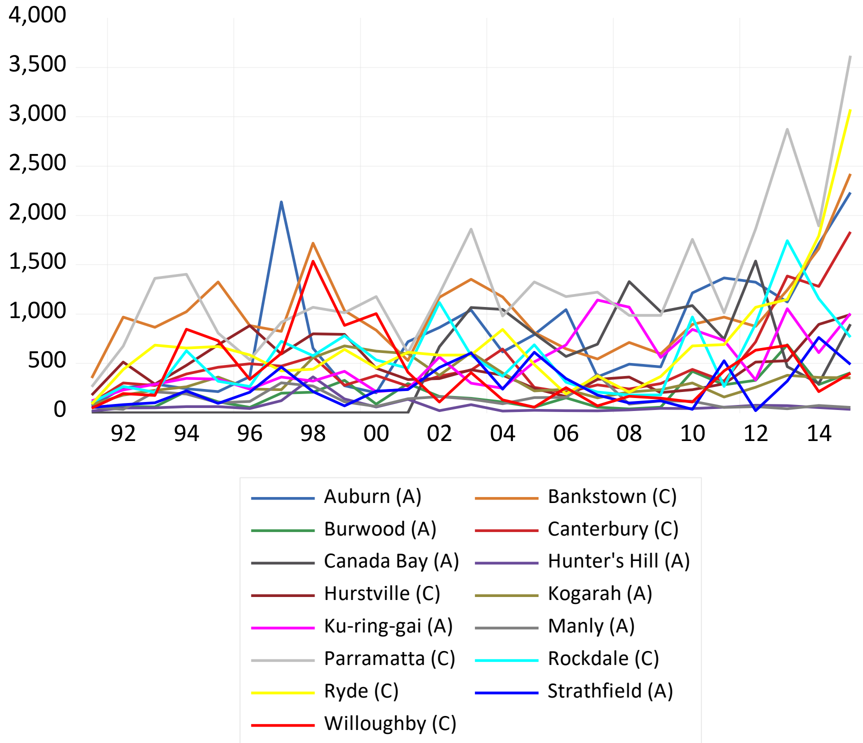


Figure 3.9.2 Strata and Non-strata Properties Approval for LGAs in the Middle Ring, 1991-2015

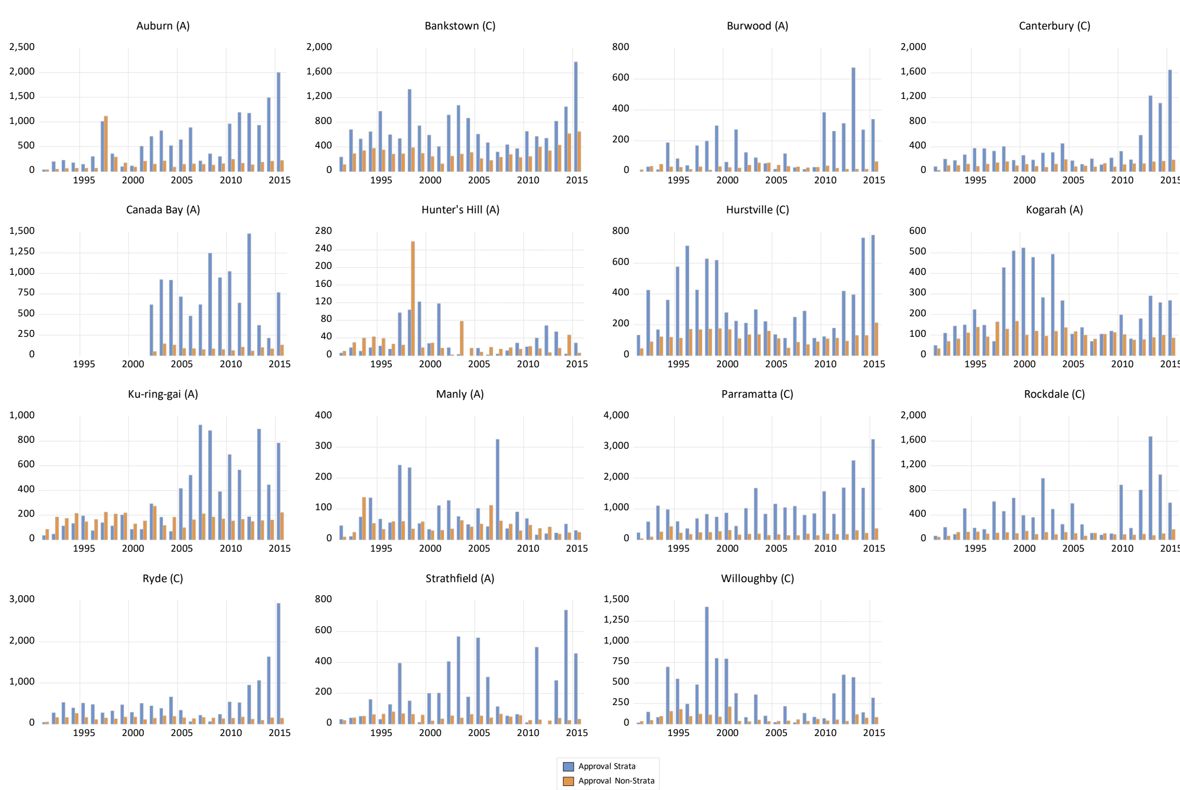


Figure 3.10.1 Total Dwelling Approval for LGAs in the Outer Ring, 1991-2015

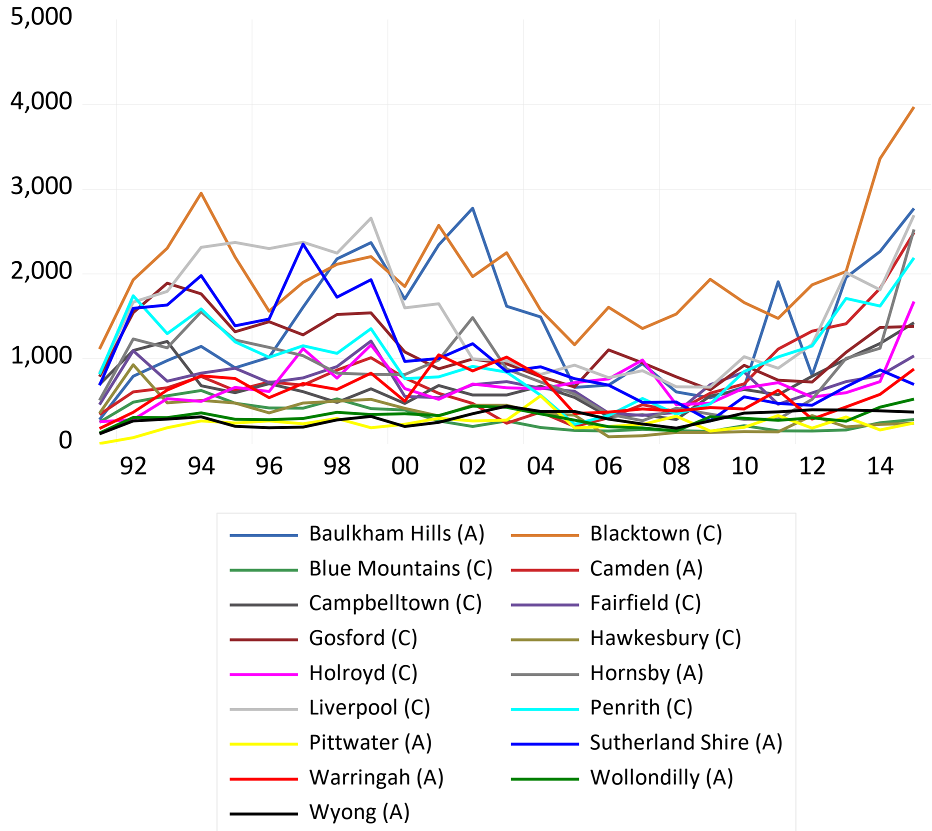
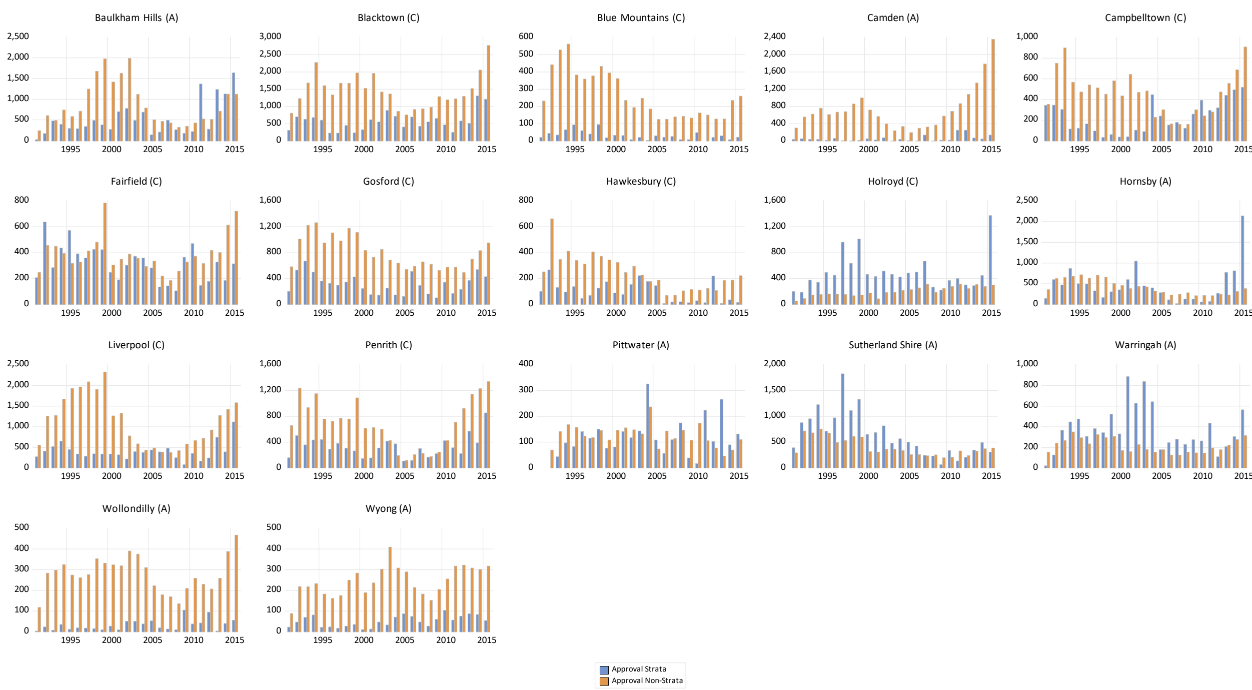


Figure 3.10.2 Strata and Non-strata Properties Approval for LGAs in the Outer Ring, 1991-2015



3.5 Concluding comments

This chapter discussed the major development in the Sydney housing market at the local governmental level over the period from 1991 to 2015. In section 3.2, we identified the three major price boom periods, namely, 1991-2003, 2004-2010 and 2011-2015. It is obvious that the first boom was the longest among the three periods. However, the boom from 2011 to 2015 had the most significant increase in real dwelling prices. Section 3.3 outlines the dwelling price differences among the three rings in metropolitan Sydney. The price movements behave in a similar pattern among the three rings, and the inner ring has the highest prices, followed by the middle ring and outer ring. Section 3.4 highlighted the dwelling stocks and development approvals in each of the LGAs. We found that development approval directly affects the amount of dwelling stock in each of the LGAs, and the type of dwelling approved tends to affect the population density and land availability in that LGA.

In chapter 4, we will employ the findings in this chapter and combined with the information mentioned in chapter 2 to provide a preliminary analysis of the data used in this thesis.

Chapter 4: Preliminary data analysis

Australia Housing Data

4.1 Introduction

As mentioned in chapter 2, the housing supply elasticity has drawn constant interest from the academic world. There are a number of studies based on different economic factors to conduct their analyses. The literature review gave a detailed description of important studies and the potential variables. Main variables such as dwelling prices, dwelling stocks, income, demographic factors, geographic factors, regulatory factors and interest rates play the most significant role in this research. The objective of this chapter is to describe the data sources to proceed a preliminary analysis of the data for selected variables and of the relationships between housing supply elasticity in each local governmental area. This chapter presents the analysis at the local government level based on the 43 LGAs in metropolitan Sydney. The local government level data are presented by aggregate data for the 43 LGAs. The regional data as a whole for these variables are aggregates of the LGA data, with the exception of price data for the region as a whole are the average of corresponding LGAs. The variables we focused on are shown in table 4.1.

Table 4.1 Main Factors

Economic Factors	Regulatory Factors	Geographic Factors
1. Income 2. Dwelling Quantities 3. Dwelling Prices 4. Interest Rates (Nominal and Real) 5. Demographic Factors (Population and Population density)	1. Development Approval (Approval number and Approval time)	1. Land Availability 2. Distance to CBD

The remaining sections of this chapter are as follows. Section 4.2 presents the sources of data for the local government level in metropolitan Sydney for the period from 1991 to 2015. Section 4.3 provides a preliminary analysis of the movement of data of all selected variables for the 43 LGAs. Finally, section 4.4 provides the conclusion.

4.2 Data from 1991-2015

This section provides detailed information about the data used in this research. Throughout the timeframe 1991 to 2015, the local governmental area boundary has changed over time. In 2011, the ABS announced the changes for ASGC to Australian Statistical Geography Standard (ASGS) from 2011 onwards (ABS, 2011). To ensure the consistency of the data used in this thesis, I used the ASGC 2006 as the base year for the entire research period due to the availability of the income and geographic factors involved in this study. Data for the 43 LGAs are converted into an annual basis from various sources for the period 1991 to 2015. To eliminate this controversy, the residential property data used in this study are classified by strata and non-strata property types. From the 2011 Census Dictionary, the Dwelling

Structure (STRD) has three broad categories for residential properties: 1. Separate house; 2. Semidetached, row or terrace house, townhouse, etc.; 3. flat, unit or apartment (ABS,2011). From the regional profile data, there are two types of residential properties: a. house and b. dwelling unit. By definition, categories 1 and 2 from the census data represents a house in regional profile data, which can be regarded as non-strata properties in our research; category 3 from the census data represents dwelling unit in regional profile data, which can be treated as strata properties. To do so, the consistency of dwelling data from different sources could be ensured.

4.2.1 Dwelling prices

The nominal house prices for strata and non-strata properties between 1991 and 2015 were found from the Rent and Sales Report published by the New South Wales Government Family and Community Services. Quarterly data for the median prices can be obtained for the 43 local government areas in metropolitan Sydney. To obtain annually-based prices, we take the average of the four quarterly data within one financial year and then generate 25 annual observations for each local governmental area in metropolitan Sydney between 1991 and 2015. The reasons for choosing this set of data are as follows: first, the data coverage of Rent and Sales Report is from 1991 to the latest timeframe; second, the median dwelling prices provide a good estimation for the housing market in terms of the development trend, which is the focus of this thesis. The real dwelling prices used in this study are proxied by nominal prices divide the CPI in Sydney.

4.2.2 Dwelling quantities

The data for dwelling quantities from the ABS. ABS collect data through the National Census of Population and Housing generated every five years. Since 1911, the census coverage has improved to more than 95% of Australians in 2016, and the reliability of the results is highly significant. However, one drawback is the frequency of this dataset, as our research is based on annual data. The way we construct the annual quantities of dwelling is by combining the census dwelling stocks for each census year (1991, 1996, 2001, 2006 and 2011) with the detailed building work approved by local governments. The monthly development approval data can be found from the New South Wales Department of Planning and Environment. To obtain the annual approval for each LGA, we take the average of monthly observations for every financial year. Then, the inter-census year dwelling data can be interpolated by table 4.2, and the methodology has been verified by Liu and Otto (2017). There are several reasons for choosing this set of data. First, the data sources are reliable and covered the entire timeframe we researched. Second, by considering development approvals, which can be a good representative for new dwelling supplied by developers.

Table 4.2 interprets the processed of interpolating dwelling stocks from a five years period to annually. From the table we define N as the inter-census year which is the year after the previous census, it is range from 1 to 5. The census data Y is from the census report, which is a five yearly data. The changes between census is calculated by using the census data at current minus the data from previous period Z1=(Y2-Y1). The development approval data is defined as X, which is an annual data. S is the sum of development approvals in the respected census period, S1=(X1+…+X5). D is the difference between actual changes and sum of development approvals, which is calculated as D1=(Z1-S1). The stock adjustment is yearly average for the difference between actual changes and sum DA, D1/5. The annual dwelling stocks for 91-92 is calculated as Y1+D1/5*N+X1, which is the sum of census data, inter-census year (N) times stock adjustment, and the development approval in that year.

Table 4.2 Interpolated Dwelling Stocks								
Financial Year	Inter-census Year N	Census data	Changes between Census	Development Approvals	Sum of Development Approvals (DA)	Differences between Actual Changes and Sum DA	Stock Adjustment	Annual Dwelling Stocks
90-91		Y1	NA	NA	NA			Y1
91-92	1			X1			D1/5	Y1+D1/5*N+X1
92-93	2			X2			D1/5	Y1+D1/5*N+X2
93-94	3			X3			D1/5	Y1+D1/5*N+X3
94-95	4			X4			D1/5	Y1+D1/5*N+X4
95-96	5	Y2	Z1=(Y2-Y1)	X5	S1=(X1+…+X5)	D1=(Z1-S1)	D1/5	Y2=Y1+D1/5*N+X5
96-97	1			X6			D2/5	Y2+D2/5*N+X6
97-98	2			X7			D2/5	Y2+D2/5*N+X7
98-99	3			X8			D2/5	Y2+D2/5*N+X8
99-00	4			X9			D2/5	Y2+D2/5*N+X9
00-01	5	Y3	Z2=(Y3-Y2)	X10	S2=(X6+…+X10)	D2=(Z2-S2)	D2/5	Y3=Y2+D1/5*N+X10

4.2.3 Real taxable income per taxpayer

The database contains annual data on real taxable income per taxpayer based on a local government level for the period 1991 to 2015 and is not available on any official Australian data sources. From data updated by Bureau of Infrastructure, Transport and Regional Economics (BITRE) in July 2014, they published taxable income databases focused on the regional areas between 1990-91 and 2005-06. As mentioned in the data description, income has been derived from the Australian Taxation Office (ATO), whose data are based on a postcode basis, and all of the money values have been adjusted by the CPI. From National Regional Profile 2007 to 2011 and 2010 to 2014 published by ABS, the nominal income per taxpayer could be found. To obtain the real income per taxpayer, the nominal data could be adjusted by the CPI. Finally, the income for 2015 is from household income and wealth, 2015-16 (ABS, 2018), and the nominal data are adjusted by CPI.

4.2.4 Interest rate

The real and nominal interest rate used in this study is obtained from the Reserve Bank of Australia (RBA). They published monthly capital market yield spreadsheets (F2) covered from 1969 to the latest month. The annual data can be computed by taking the average of monthly data within the financial year. The real interest rate is the Australian Government Indexed Bond rate, and the nominal interest rate is the 10-year government bond rate.

4.2.5 Population

The population for each LGA based on ASGC 2006 could be found from ABS. The regional population growth report provides the estimated population in each LGA in metropolitan Sydney from 1991 to 2015.

4.2.6 Geographic data

Based on the definition given by Liu and Otto (2017), land in each LGA has been divided into 5 categories: Geo_1, Geo_2, Geo_3, Geo_4 and Geo_5. Due to the restriction on data accessibility, all five categories of geographic data used in this study are from Professor Glenn Otto's database. They constructed their data from three satellite-based sources: First, the GEODATA TOPO 250 K Series 3, which is published jointly by the National Topographic Map Series and Defense Joint Operation Graphics. Second, Geoscience Australia has published Digital Elevation Data, which describes the landforms of Australia. Finally, the ABS published the Statistical Geography based on 2006 data, and the ASGC and the Digital Boundaries were formed from that.

Table 4.3 Geographic Variables

Geographic Variables	Definition
Geo_1	Under the specific natural geographic features introduced by Saiz (2010), the amount of land is unable for housing development activities is measured by Geo_1.
Geo_2	The amount of land local government specifically designed for future public facilities purpose plus the amount land defined by Geo_1.
Geo_3	Australian Road Rules has defined the meaning of built-up area, from their definition, Geo_3 measures the amount land which LGA treated as built-up area.
Geo_4	The sum of Geo_1, Geo_2 and Geo_3.
Geo_5	The amount of land regarded as Recreation areas in 2006 is measured by Geo_5.

4.2.7 Development approval

Development approval is the legal document for local government to process a development activity. It measures the time length of the approval and the amount of properties approved. The New South Wales Government Department of Planning and Environment published monthly data for different types of dwellings approved by the local government. The annual data could be computed by finding the average within a financial year. The reason for choosing this set of data is that first, the data source is reliable from the ABS, and it has been retrospectively revised by the ABS; second, the data coverage of these data source satisfied the needs of our analysis from 1991 to 2015.

Table 4.4 Summary information

Variable	Data Period	Data Frequency	Data Description	Data Sources
Dwelling Prices	The Metropolitan LGAs in the State of New South Wales: 1991-2015	Quarterly	Median dwelling prices for strata and Non-strata Properties	The New South Wales Government Department of Family and Community Services (Issue 120, 2017)
Dwelling Quantities	The National Census of Population and Housing (1991, 1996, 2001, 2006 and 2012)	5 yearly	Number of different types of dwellings: Strata and Non-strata	The Australian Bureau of Statistics (ABS)
Real Taxable Income Per Taxpayer	Regional economic growth: Taxable Income Database 1990-2006; National Regional Profile 2007 to 2011 and 2010 to 2014	Annually	Taxable Income Real Income Per Taxpayer	The Bureau of Infrastructure, Transport and Regional Economics (BITRE), Regional Databases The ABS
Real Interest Rate	Australian Government Bond 1991-2015	Monthly	Australian Government Indexed Bond Rate	The Reserve Bank of Australia, Capital Market Yields-Government Bonds-Monthly Table F2
Nominal Interest Rate	Australian Government Bond 1991-2015	Monthly	10-Year Australian Government Bond Rate	The Reserve Bank of Australia, Capital Market Yields-Government Bonds-Monthly Table F2
Population	Regional Population Growth 1991-2015	Yearly	Estimated population by LGAs	The Regional Population Growth Report, by the ABS
Geographic Data	Australian Standard Geographical Classification (ASGC) 2006	Derived from ASGC 2006, Fixed Data	The Land Unavailability in Each LGA	GEODATA TOPO 250K SERIES 3 SRTM DIGITAL ELEVATION DATA, AUSTRALIA Local Government Area Digital Boundaries
Development Approval	Greater Sydney Regional Housing Activity 1991-2016	Monthly	The Number of New residential properties approved by LGAs: Strata and Non-strata Properties	The New South Wales Government Department of Planning and Environment

4.3 Preliminary analysis of the housing data for metropolitan Sydney as a whole

In this section, we present a preliminary analysis of the previously discussed variables sorted out by three geographic regions: the inner ring, the middle ring and the outer ring. The trends for the 43 individual LGAs during the period 1991 to 2015 will be analyzed.

Table 4.4 Grouping of LGAs

Inner Ring (11)	Middle Ring (15)	Outer Ring (17)
Ashfield	Auburn	Baulkham Hills
Botany	Bankstown	Blacktown
Lane Cove	Burwood	Blue Mountains
Leichhardt	Canterbury	Camden
Marrickville	Canada Bay	Campbelltown
Mosman	Hunters Hill	Fairfield
North Sydney	Hurstville	Gosford
Randwick	Kogarah	Hawkesbury
Sydney	Ku-ring-gai	Holroyd
Waverley	Manly	Hornsby
Woollahra	Parramatta	Liverpool
	Rockdale	Penrith
	Ryde	Pittwater
	Strathfield	Sutherland
	Willoughby	Warringah
		Wollondilly
		Wyong

4.3.1 Real dwelling prices and related variables

In chapter 3, we discussed the nominal and real dwelling price movements for metropolitan Sydney as a whole. From figure 3.1, the trends for the normal HPI and RHPI for strata, non-strata and all properties in metropolitan Sydney between 1991 and 2015 can be identified. Three major price booms in metropolitan Sydney were found in 1991-2003, 2004-2010, and 2012-2015. What happened in each LGA from the three regional groups will be presented.

Figure 4.1.1 Median Nominal Prices for Different Dwellings in the LGAs (Inner Ring)

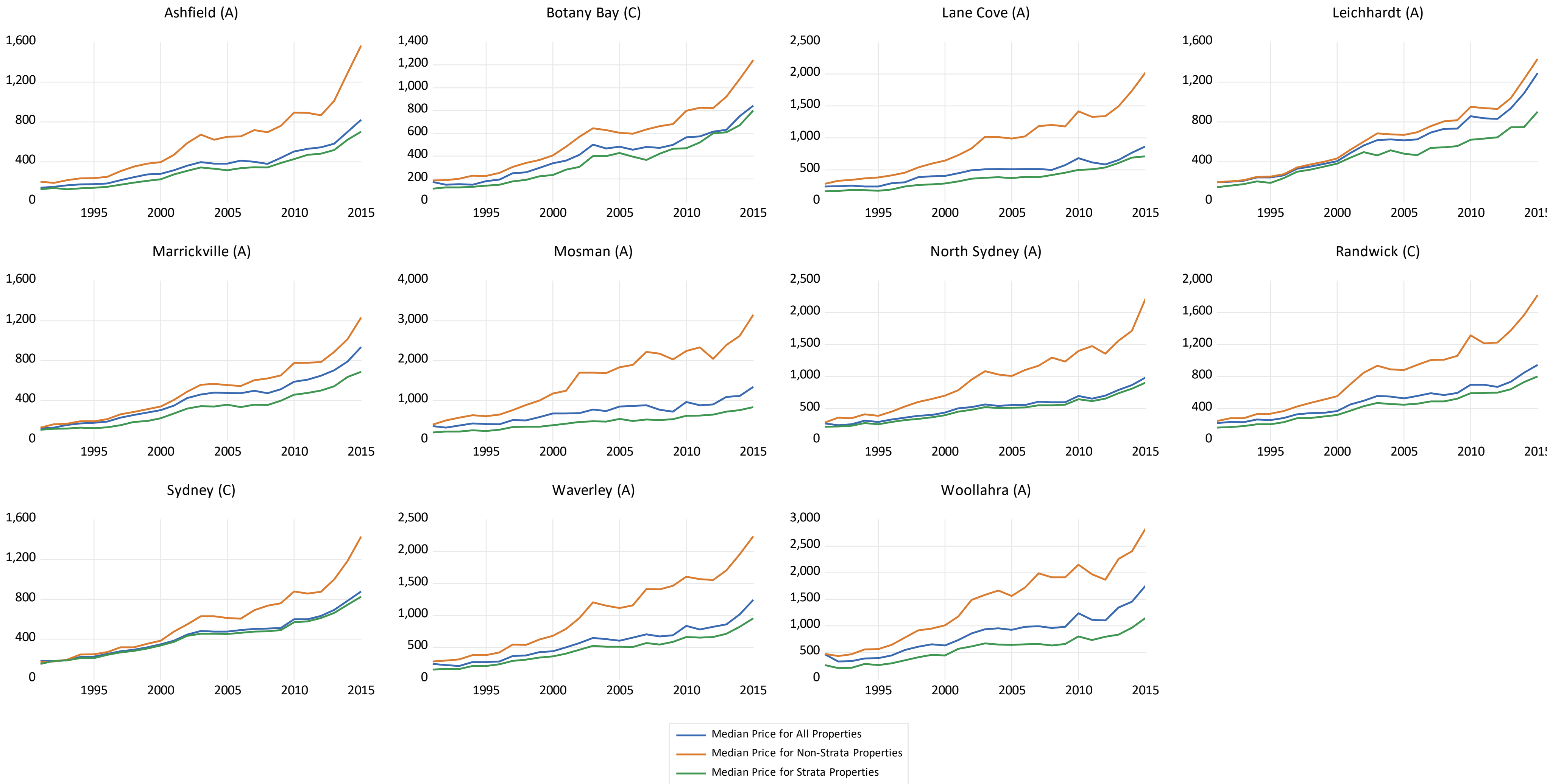


Figure 4.1.1 shows the median nominal prices for different dwellings in the inner ring metropolitan Sydney. All of the 11 LGAs have a similar increasing trend between 1991 and 2015, which is consistent with the trends in figure 3.1 shown in chapter 3. For the nominal median prices of non-strata properties, Lane Cove, Mosman, North Sydney, Waverley and Woollahra reached a high price in 2015, which is above 2 million Australia dollars. This high price is due to the high population density and amount of land available for development in each of the LGAs. Compared with the strata properties, the non-strata properties nominal prices increase with more fluctuation trends.

Figure 4.1.2 shows the median real prices for different dwellings in the inner ring metropolitan Sydney. All of the 11 LGAs have a similar increasing trend between 1991 and 2015, which is consistent with the trends in figure 3.2 shown in chapter 3. For the median prices of non-strata properties, Mosman, North Sydney, Waverley and Woollahra reached a high real price in 2015, which is above 20. Compared with nominal dwelling prices, real prices fluctuate more between 1991 and 2015, which indicates real-term dwelling price changes.

Figure 4.1.2 Median Real Prices for Different Dwellings in the LGAs (Inner Ring)

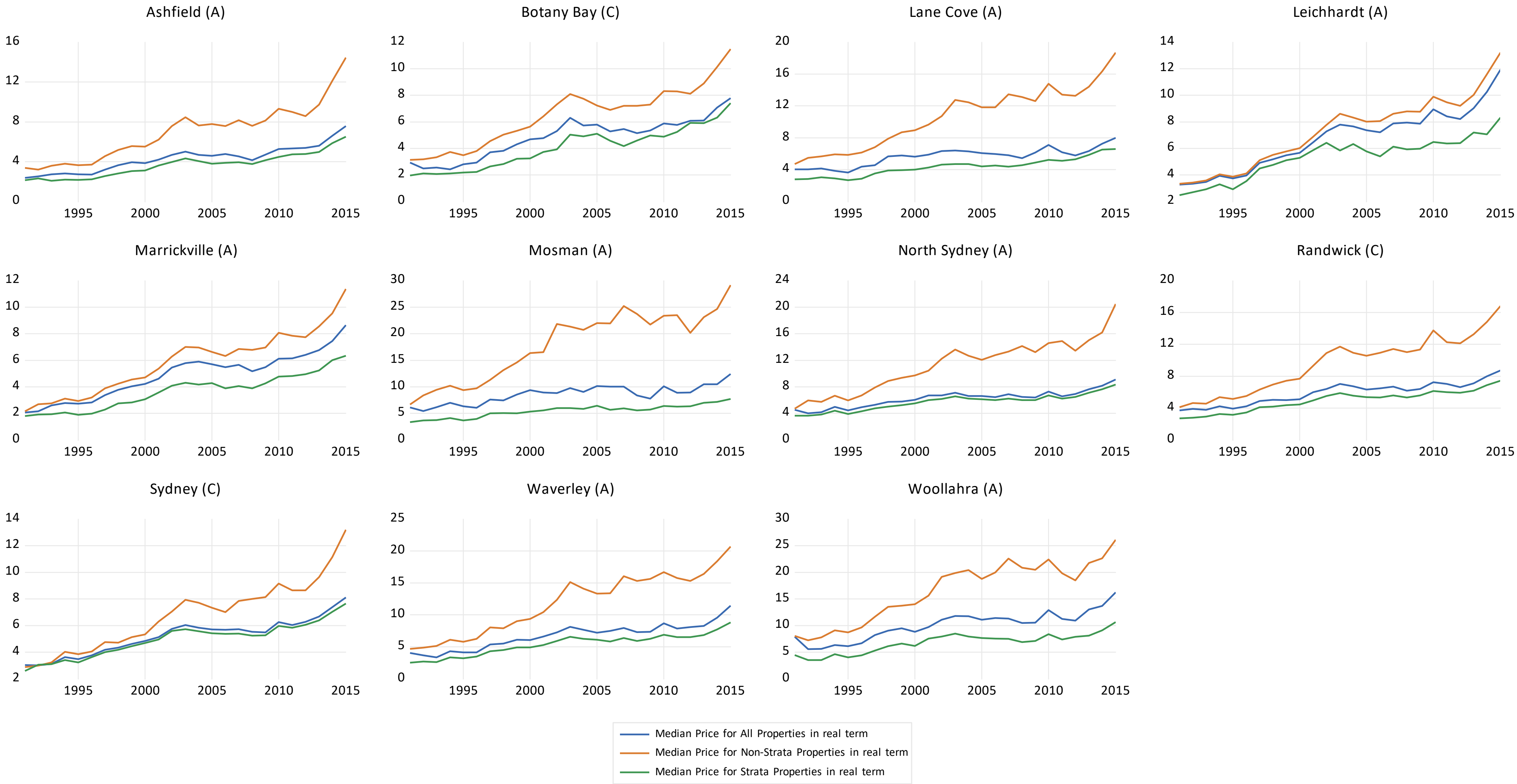


Figure 4.2.1 Median Nominal Prices for Different Dwellings in the LGAs (Middle Ring)

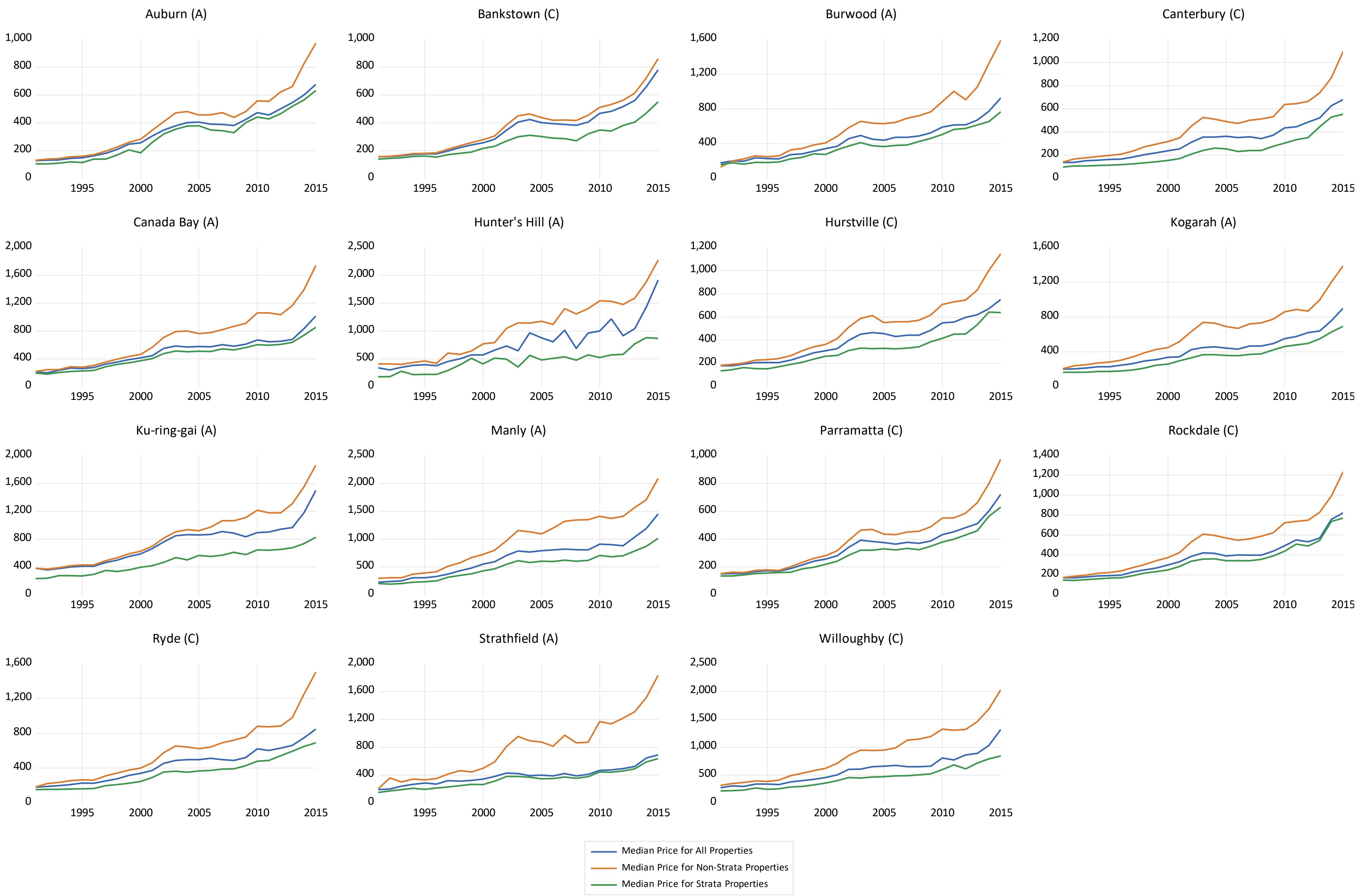


Figure 4.2.1 shows the median nominal prices for different dwellings in the meddle ring metropolitan Sydney. All 15 LGAs have a similar increasing trend between 1991 and 2015, which is consistent with the trends in figure 3.1 shown in chapter 3. For the nominal median prices of non-strata properties, Burwood, Canterbury, Canada Bay, Hunters Hill, Ku-ring-gai, Manly, Strathfield, and Willoughby reached a high price in 2015, which is above 1.6 million Australia dollars. The reason for this is mainly due to the high population density in each of the LGAs. Compared with the strata properties, the non-strata properties nominal prices increase with more fluctuation trends.

Figure 4.2.2 shows the median real prices for different dwellings in the meddle ring metropolitan Sydney. All 15 LGAs have a similar increasing trend between 1991 and 2015, which is consistent with the trends in figure 3.2 shown in chapter 3. For the median prices of non-strata properties, Canterbury, Canada Bay, Hunters Hill, Ku-ring-gai, Manly, Strathfield, and Willoughby reached a high real price in 2015, which is above 16. Compared with nominal dwelling prices, real prices fluctuate more between 1991 and 2015, which indicates real-term dwelling price changes.

Figure 4.2.2 Median Real Prices for Different Dwellings in the LGAs (Middle Ring)

Figure 4.3.1 Median Nominal Prices for Different Dwellings in the LGAs (Outer Ring)

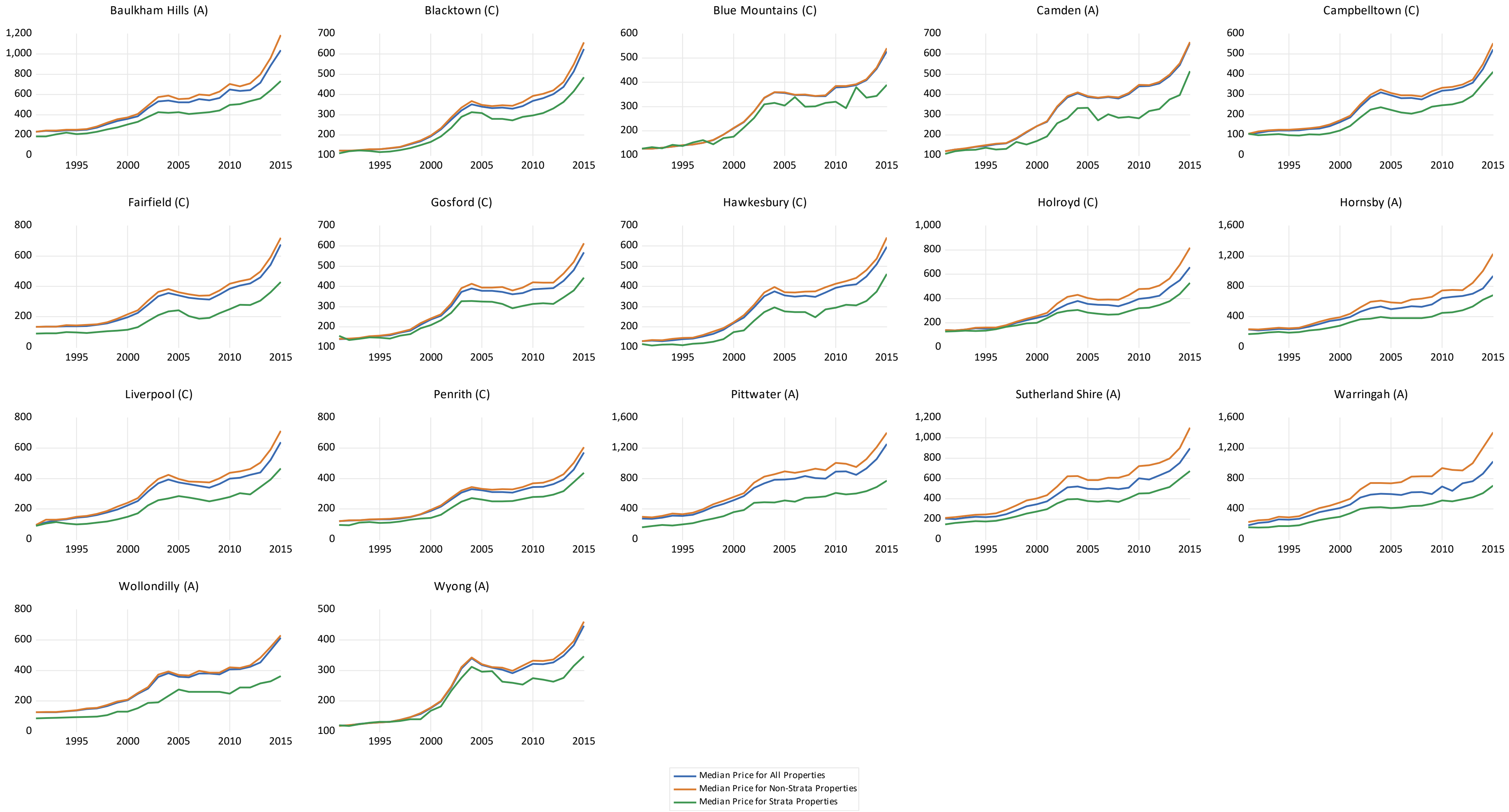
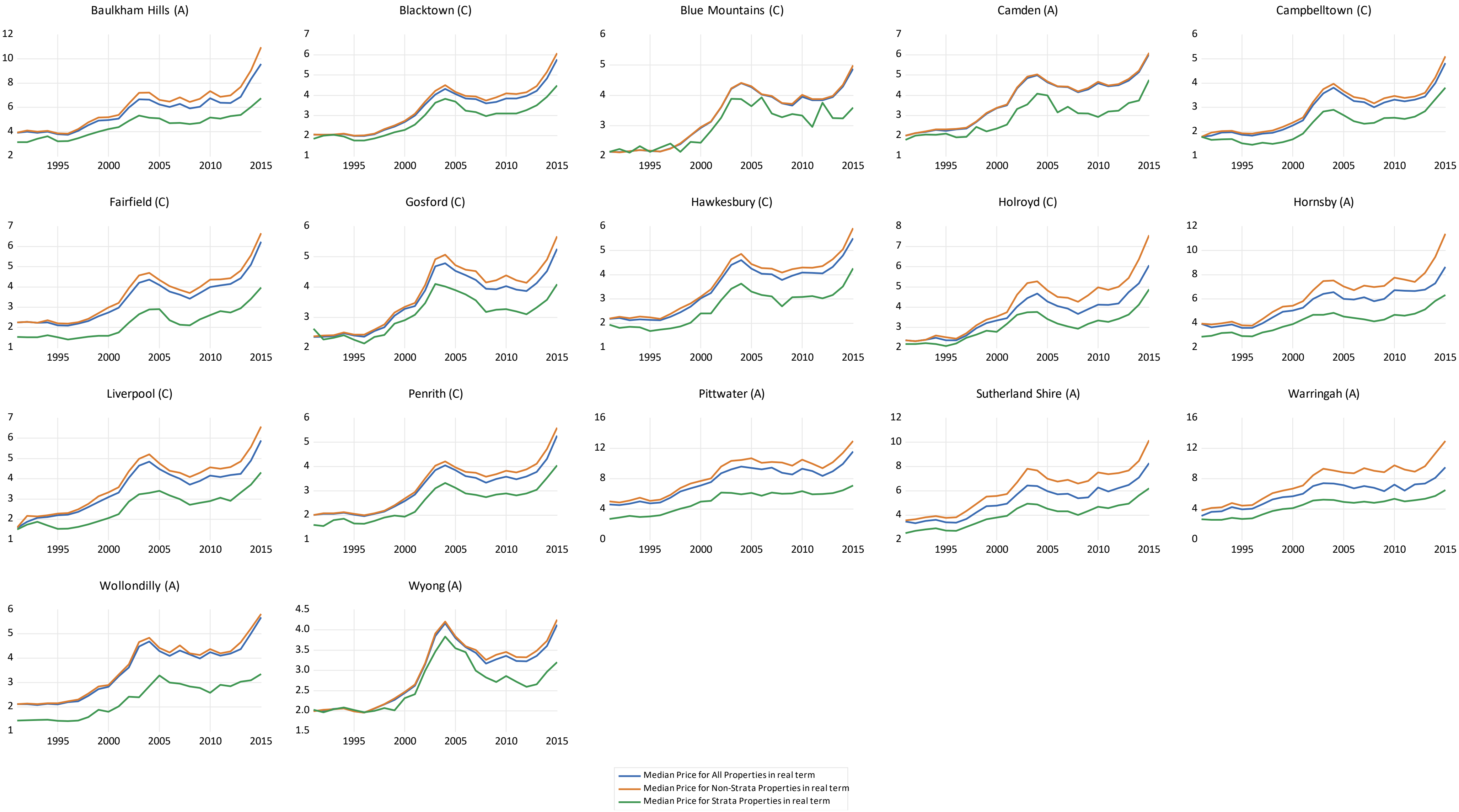


Figure 4.3.1 shows the median nominal prices for different dwellings in the outer ring metropolitan Sydney. All of the 17 LGAs have a similar increasing trend between 1991 and 2015, for the nominal median prices of non-strata properties, Baulkham Hills, Hornsby, Pittwater, and Warringah reached a high price in 2015, which is above 1.2 million Australia dollars. The reason for this is that the strict development restrictions each of the LGAs and the proportion of land available for development are limited due to geographic reasons. Compared with the inner ring and meddle ring, the outer ring has a different trend, with the first maximum point occurring around 2003 and then steady increase to 2015.

Figure 4.3.2 shows the median real prices for different dwellings in the outer ring metropolitan Sydney. All of the 17 LGAs have a similar increasing trend between 1991 and 2015, for the median prices of non-strata properties, Baulkham Hills, Hornsby, Pittwater, and Warringah reached a high real price in 2015, which is above 10. Compared with nominal dwelling prices, real prices fluctuate more between 1991 and 2015, which indicates real-term dwelling price changes.

Figure 4.3.2 Median Real Prices for Different Dwellings in the LGAs (Outer Ring)



4.4 Conclusion

In this chapter, we discussed the variables used in this thesis and the sources of these housing data and then presented a preliminary analysis of the dwelling price movements using graphs. Section 4.2 provides the sources of datasets. In section 4.3, we separate 43 metropolitan Sydney local governmental areas into 3 rings. By using graphs, we individually analyzed each type of dwelling in the inner, middle and outer rings and then show the different trends of nominal and real price changes. As the figures show, the trends in the inner and middle rings are almost consistent with the metropolitan Sydney housing market as a whole. On the other hand, the outer ring has a two time-period increasing trend, which is different from the general trend shown in chapter 3.

Chapter 5: Modeling housing supply elasticity in Sydney

5.1 Introduction

The preliminary analysis provided annual data for 43 local governmental areas in metropolitan Sydney over 25 years (1991-2015). To determine the changes in supply elasticity throughout the timeframe, we run regressions to obtain valid supply elasticity estimation on the individual LGAs for strata and non-strata properties.

The remaining sections of this chapter are as follows. Section 5.2 discusses the model development. Section 5.3 estimates the supply elasticity in each LGA for different types of dwellings in the two time periods and tests for the quality of instruments used in the regression. Section 5.4 applies cross-section analysis on the determinants of the supply elasticity variation. Section 5.5 discusses the determinants of supply elasticity. Finally, section 5.6 provides a nutshell summary of the modeling section.

The statistical significance level used in this chapter is 10%.

5.2 Model development

Elasticity measures the sensitivity of one variable with respect to the change in another variable. Topel and Rosen (1988) have discussed the importance of housing supply elasticity towards the changes in housing prices and the volatilities in housing investments. Based on their research, Mulligan (2010) defined the elasticity of housing supply as "the effect on the flow of home building (measured as a log change — think of it as a percentage change) of the inflation-adjusted purchase price of housing (also measured as a log change)". Gitelman and Otto (2012) established a model on the definition:

$$\epsilon_I^S = \frac{\Delta I^h}{\Delta P}\frac{P}{I^h} \tag{5.1}$$

The I^h measures the flow of home building; it has two components: the changes in housing stocks ΔH and the depreciation in housing stock δH. The inflation-adjusted purchase prices are measured by P. Based on the research conducted by Green, Malpezzi and Mayo in 2005, the model used in this study is similar to their approach combined with the early studies on stock-adjustment modeling from a supply side of the existing housing stock (DiPasquale and Wheaton 1991, Mayer and Somerville 2000, and Malpezzi and Maclennan 2001). The housing supply is measured directly by the housing prices and potential endogenous variables in modeling supply elasticity. In this thesis, we assume that the market conditions are homogeneous. Therefore, the adjustment speed for housing markets in 43 individual LGAs is identical. From a stock-adjustment model, the supply curve for a particular local government area can be determined by:

$$lnQ_t^n = \alpha^n + \beta^n lnP_t^n + u_t^n \tag{5.2}$$

where Q_t^n represents the housing stock at time t for nth local government area, and P_t^n represents the housing prices at time t for nth local government area. Using the slope expression, β^n represents the housing supply elasticity in nth local government area. Using equations (5.1) to (5.2), we take the logarithms of the dependent, independent and explanatory variables. There are two reasons for taking the logarithm: first, it normalizes the data, which reduces the extremely skewed distribution to make it more symmetric; second, it makes a better fit for the dataset to the regression curve. It is obvious that the model is very restricted, as we considered only the dwelling prices and quantities. Due to the lack of data, there are a number of variables omitted in this study that could affect the housing supply, for example, the productivity level in new houses, the factor prices in construction processes, the expectations on the future housing market in terms of prices, and the government influences, including estate taxes and regulations. Under current circumstances, these variables are not available at the level of government this research focused on. Additionally, running a regression use equation (5.2), due to the omitted potential endogenous variables, will produce biased and inconsistent estimation, which is known as omitted-variable bias. The potential problem for the least squares estimator arises when the explanatory variable and the error term are correlated, which means that the explanatory variable is endogenous. In our research, which will lead to $E[\ln P_t^n u_t^n] \neq 0$ in equation (5.2), which makes the moment condition for OLS invalid by introducing another variable Z, such that:

1. Z does not have a direct effect on the dependent variable and thus does not belong on the right-hand side of the model as an explanatory variable.
2. Z does not correlate with the regression error term e, which indicates that it is exogenous.
3. Z has a strong or at least not weakly correlation with the independent variable, which in the model is the endogenous explanatory variable.

Following the steps from previous supply-side studies. In 1981, Wheaton estimated the demand curve with exogenous variables, for example, periodic income, population, housing prices, different types of holding costs and various interest rates. In 2001, Malpezzi and Maclennan used the simple reduced-form equation as a procedure to model house prices as a function of income, population and housing stocks. In 2012, Gitelman and Otto used four instrument variables, namely, income, house prices, population and real and nominal interest rates, to estimate supply elasticity. Based on equation (5.2) and Gitelman and Otto's model (2012), the inversed demand curve for house could be formulized by including an exogenous variable Z, which can be excluded from the supply curve. The equation is as follows:

$$\ln P_t^n = \alpha^n + \beta^n \ln Q_t^n + Z_t'^n \Gamma^n + e_t^n \tag{5.3}$$

In this research, $Z_t'^n$could include three of the instruments from Gitelman and Otto in 2012: real income per tax payer, population in each LGA and the real interest rate. Running a regression using equation (5.3) will produce biased and inconsistent estimation due to the omitted potential endogenous variables, which is known as omitted-variable bias. To address this problem, the instrumental variables from $Z_t'^n$ could be taken into account. By using instrumental variables, potentially the error term u_t^n facing serial correlation and heteroskedasticity. From equations (5.2) and (5.3), both the housing prices and the housing stocks are log values. It is important to know whether the time series data are stationary or nonstationary. If the log variables have been nonstationary presented a stochastic trend, there is a danger of obtaining apparently significant regression results from unrelated data when nonstationary series are used in regression analysis, i.e., the regression is spurious. When the housing prices and stocks have a stochastic trend, in order for the regression to be valid, the error term u_t^n must be stationary, and the log prices and quantities must be co-integrated. Otherwise, the instrument variable estimation is inconsistent.

Based on the research taken by Liu and Otto (2017), the instruments used in this research are real income per tax payer, the population in each LGA, and the real interest rate. As we can see from the preliminary data analysis chapter, the first two instruments are various among the 43 LGAs; however, the 10-year government bond rate is the same in all 43 LGAs. The reduced-form model can be established as follows:

$$\ln P_t^n = \pi_0^n + \pi_i^n \ln income_t^n + \pi_p^n \ln population_t^n + \pi_r^n \ln rinterest_t + e_t^n \quad (5.4)$$

5.3 Model estimation

In this section, we first test the instrument quality and then estimate the supply elasticity in each of the local government areas.

5.3.1 Instrument viability

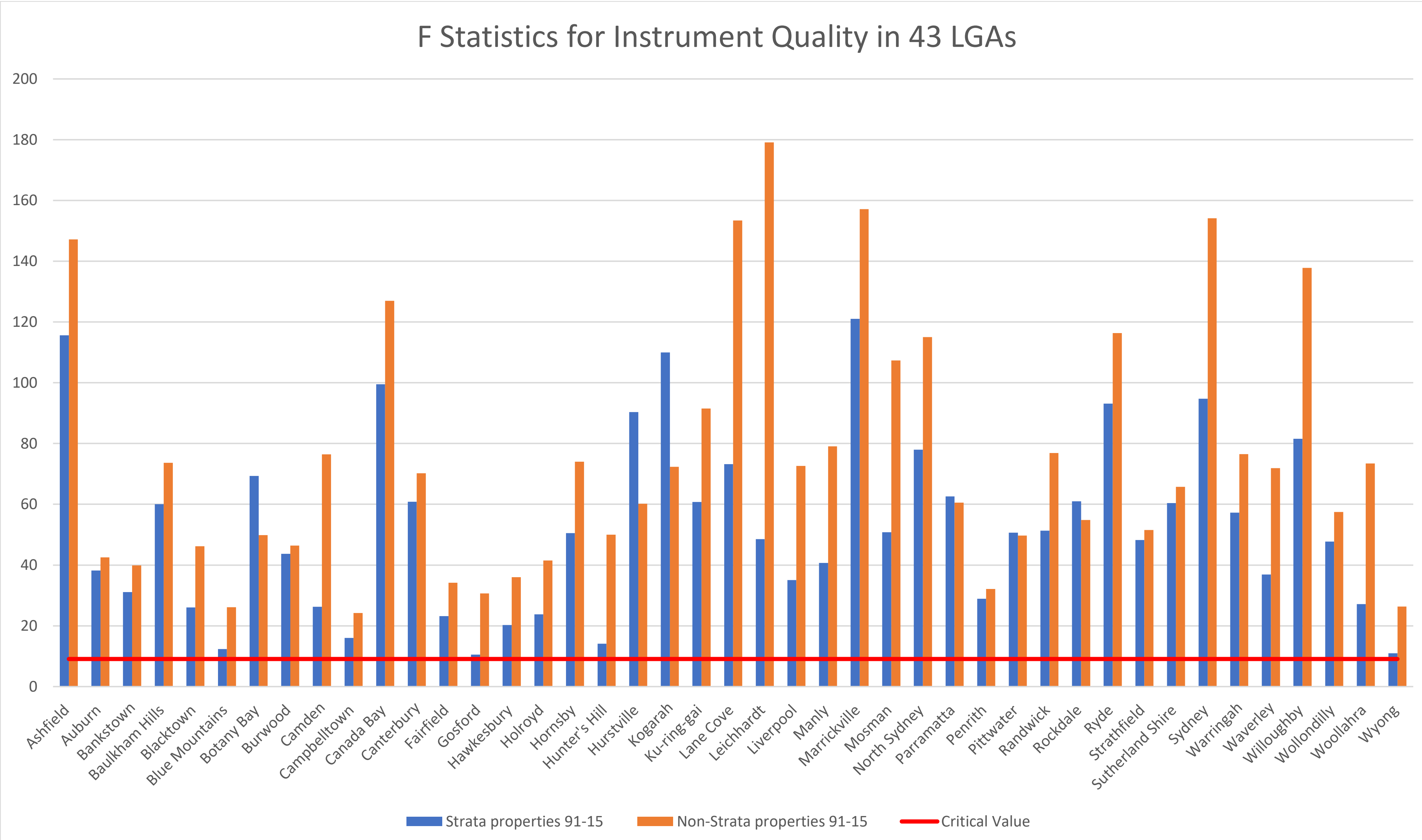
From equation (5.4), we have established a reduced-form model with real income per tax payer, the population in each LGA, and the real interest rate as the instrumental variables. The dependent variable $\ln P_t^n$ stands for the log value of the real dwelling prices at time t in the nth local government area. the explanatory variables $\ln income_t^n$, $\ln population_t^n$, $\ln rinterest_t$ measures the real income per tax payer, the population and the real interest rate for time t at the nth local government area. The dependent variable $\ln P_t^n$ and the first two explanatory variables $\ln income_t^n$ and $\ln population_t^n$ varied among the 43 LGAs, and the real interest rate remained the same for all of them. To test the exogeneity and relevance of the instruments, a study on "Testing for Weak Instruments in Linear IV Regression" performed by Stock and Yogo (2002) could be applied. Based on their findings, the critical value for the weak instrument test based on two-stage least squares (TSLS) bias at a 5% significance level is 9.08 (Stock, Yogo, 2003). Using equation (5.4), the results of a TSLS regression with real income per tax payer, the population in each LGA, and the real interest rate as the instrumental variables are shown in table (5.1). Table (5.1) shows the F statistics for strata and non-strata properties in metropolitan Sydney between 1991 and 2015, when the coefficient terms of the explanatory variables $\pi_i = \pi_p = \pi_r = 0$. Combined with the critical value from Stock and Yogo (2003) and the F Statistics from table 5.1, all of the results for 43 LGAs are greater than 9.08, so there is evidence that the hypothesis is rejected at a 5% significance level. The results can also be emphasized by figure 5.1, as all of the vertical histograms have a value above the horizontal red line, which indicates a critical value of 9.08. In conclusion, the weak instruments used in this thesis will not be a serious issue to apply those three explanatory variables as the instrument variables to estimate the housing supply elasticity in metropolitan Sydney.

Table 5.1 F Statistics for LGAs

LGA Name	Strata properties 91-15	Non-strata properties 91-15
	F-test	F-test
Ashfield	115.611	147.185
Auburn	38.206	42.503
Bankstown	31.113	39.871
Baulkham Hills	60.023	73.649
Blacktown	26.029	46.221

Blue Mountains	12.341	26.091
Botany Bay	69.362	49.861
Burwood	43.679	46.380
Camden	26.270	76.437
Campbelltown	15.997	24.214
Canada Bay	99.539	126.997
Canterbury	60.809	70.223
Fairfield	23.229	34.175
Gosford	10.539	30.639
Hawkesbury	20.275	36.000
Holroyd	23.765	41.514
Hornsby	50.535	74.023
Hunter's Hill	14.080	49.969
Hurstville	90.366	60.188
Kogarah	110.015	72.335
Ku-ring-gai	60.767	91.491
Lane Cove	73.203	153.418
Leichhardt	48.540	179.150
Liverpool	35.072	72.613
Manly	40.716	79.064
Marrickville	121.011	157.138
Mosman	50.784	107.309
North Sydney	77.952	115.030
Parramatta	62.561	60.528
Penrith	28.885	32.136
Pittwater	50.660	49.741
Randwick	51.285	76.846
Rockdale	60.961	54.839
Ryde	93.107	116.366
Strathfield	48.235	51.523
Sutherland Shire	60.428	65.773
Sydney	94.755	154.111
Warringah	57.265	76.528
Waverley	36.895	71.872
Willoughby	81.595	137.844
Wollondilly	47.730	57.443
Woollahra	27.166	73.414
Wyong	10.943	26.344

Figure 5.1 F Statistics for Instrument Quality in 43 LGAs



5.3.2 Supply elasticity estimation

From section 5.3.1, we have examined the quality of instrumental variables. By applying TSLS regression on equation (5.2) $lnQ_t^n = \alpha^n + \beta^n lnP_t^n + u_t^n$, with real income per tax payer, the population in each LGA, and the real interest rate as the instrumental variables, we could estimate the supply elasticity for different types of dwellings in metropolitan Sydney. Table 5.2 below shows the supply elasticity estimations for strata and non-strata properties in the 43 LGAs.

Table 5.2 Supply elasticity estimations for 43 LGAs

LGA Name	Strata properties 1991-2015		Non-strata properties 1991-2015	
	Supply elasticity	Standard error	Supply elasticity	Standard error
Ashfield	0.19	0.02	0.08	0.01
Auburn	1.15	0.11	0.24	0.02
Bankstown	1.80	0.19	0.17	0.01
Baulkham Hills	4.45	0.29	0.64	0.04
Blacktown	1.28	0.15	0.45	0.03
Blue Mountains	-0.62	0.16	0.29	0.02
Botany Bay	0.50	0.07	0.15	0.01
Burwood	0.64	0.04	0.10	0.01
Camden	0.43	0.18	1.05	0.07
Campbelltown	0.98	0.23	0.26	0.02
Canada Bay	0.63	0.07	0.14	0.01
Canterbury	0.24	0.02	0.10	0.01
Fairfield	0.26	0.03	0.18	0.01
Gosford	1.25	0.24	0.37	0.03
Hawkesbury	0.29	0.05	0.31	0.03
Holroyd	1.32	0.13	0.22	0.02
Hornsby	1.37	0.09	0.24	0.02
Hunter's Hill	0.56	0.08	0.20	0.01
Hurstville	1.00	0.05	0.12	0.01
Kogarah	0.87	0.06	0.08	0.01
Ku-ring-gai	1.66	0.26	0.09	0.01
Lane Cove	0.46	0.05	0.06	0.01
Leichhardt	0.67	0.04	0.13	0.01
Liverpool	0.44	0.07	0.67	0.04
Manly	0.18	0.03	0.13	0.01
Marrickville	0.29	0.02	0.08	0.01
Mosman	0.25	0.02	0.07	0.01

North Sydney	0.53	0.03	0.20	0.02
Parramatta	1.04	0.08	0.15	0.01
Penrith	0.64	0.08	0.34	0.03
Pittwater	0.37	0.06	0.22	0.02
Randwick	0.36	0.03	0.11	0.01
Rockdale	0.65	0.04	0.08	0.01
Ryde	0.59	0.05	0.10	0.01
Strathfield	1.95	0.26	0.09	0.01
Sutherland Shire	0.86	0.07	0.20	0.01
Sydney	1.63	0.09	0.20	0.02
Warringah	0.62	0.06	0.12	0.01
Waverley	0.28	0.03	0.09	0.01
Willoughby	1.40	0.10	0.08	0.00
Wollondilly	0.96	0.21	0.51	0.03
Woollahra	0.27	0.03	0.09	0.02
Wyong	1.12	0.26	0.56	0.05

Figure 5.2 Supply Elasticity Estimation for Strata Property in 43 LGAs

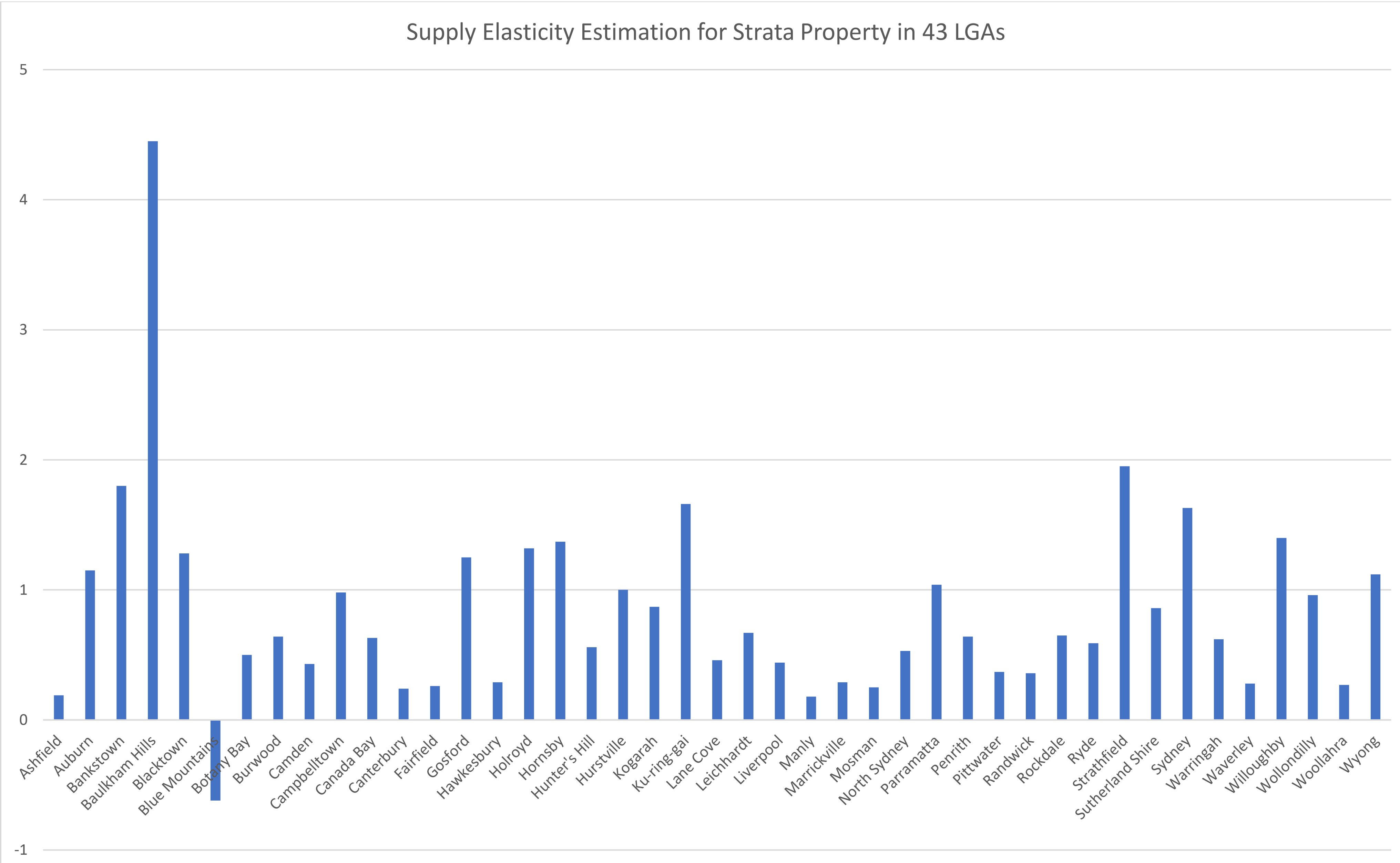


Figure 5.3 Supply Elasticity Estimation for Non-strata Property in 43 LGAs

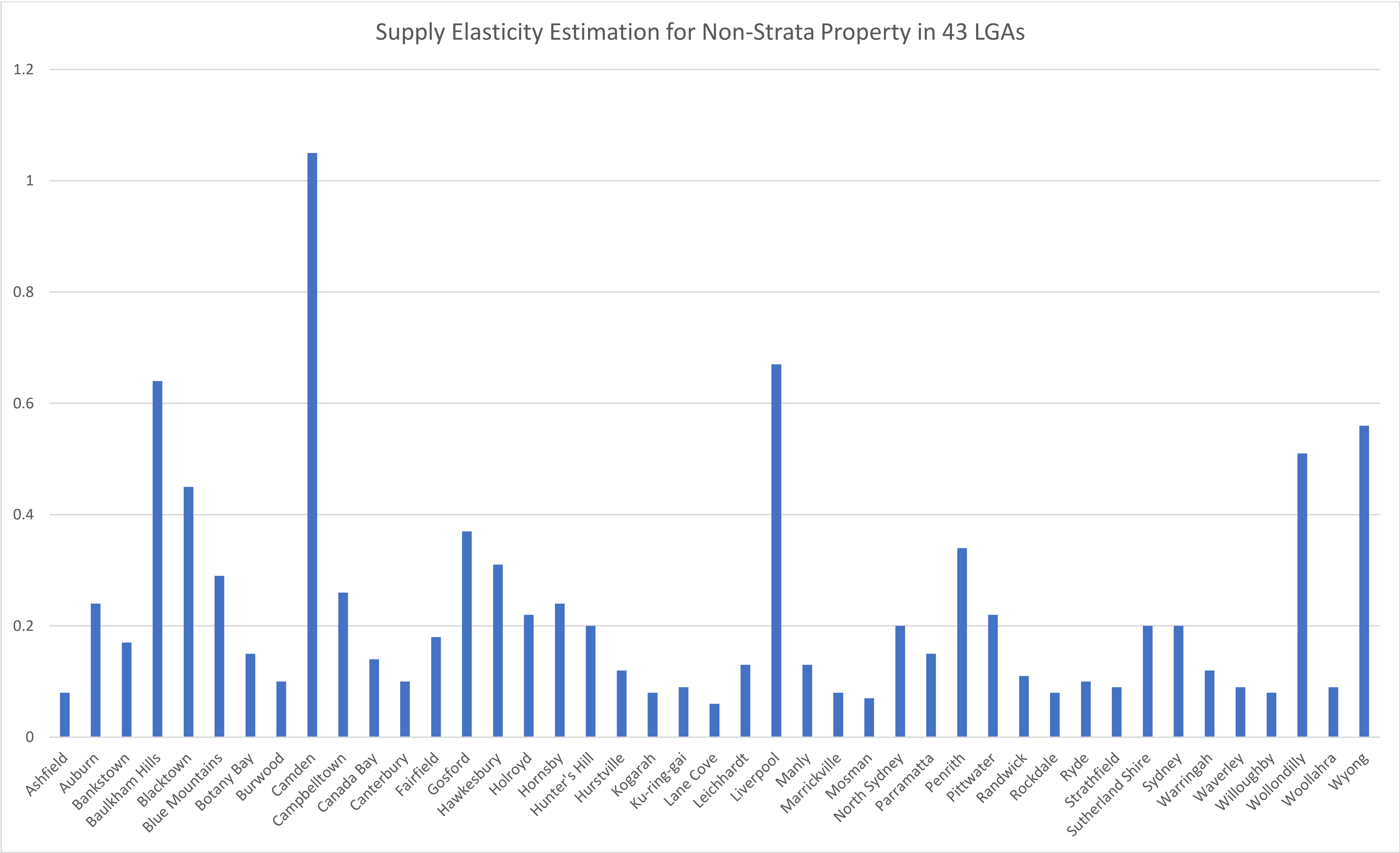
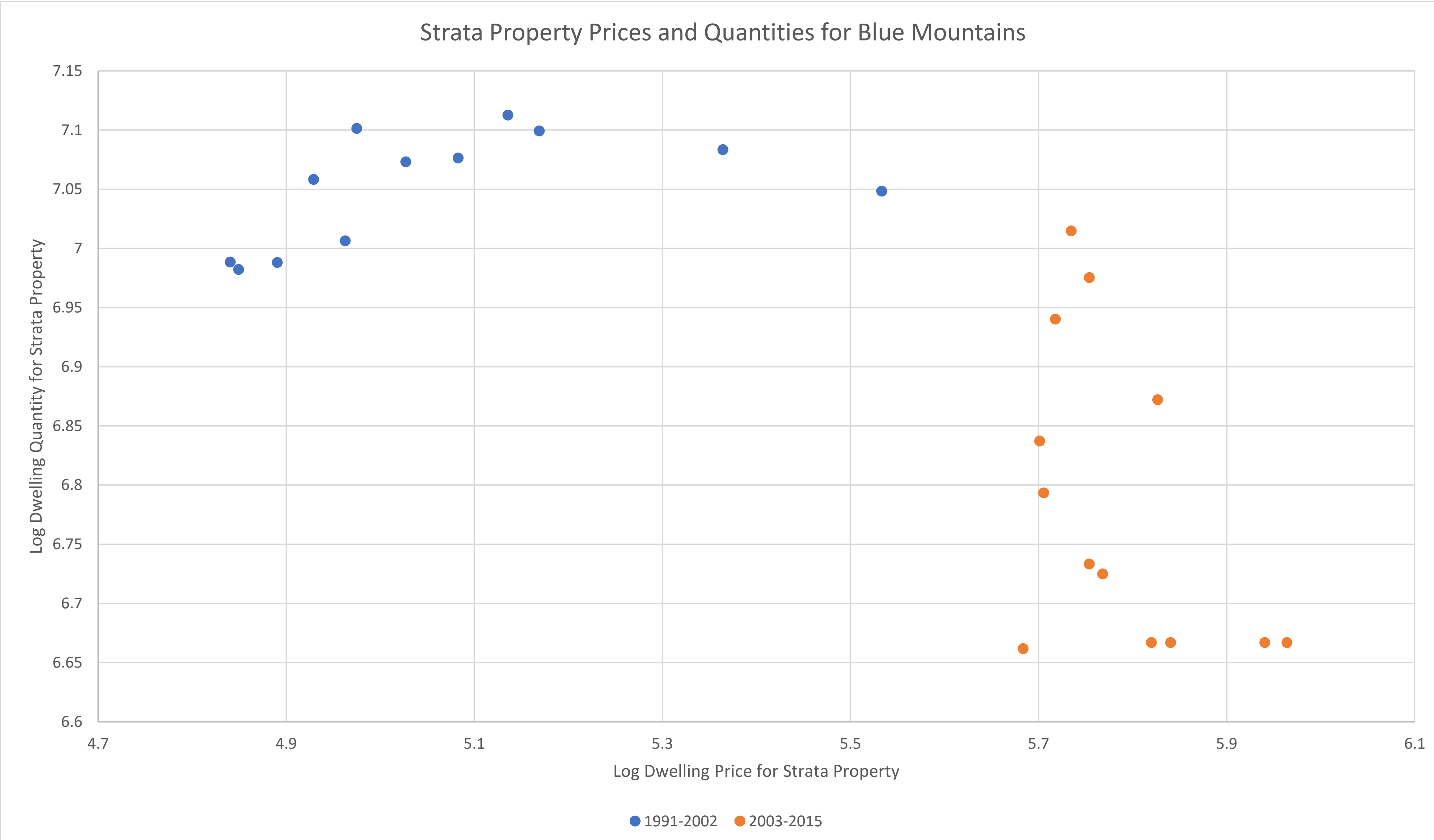


Table 5.2 reports the supply elasticity estimations for strata and non-strata properties in the 43 LGAs. It is obvious that the supply elasticity for non-strata properties is inelastic in 42 LGAs with an average of 0.23; the only exception occurs in Camden with a value of 1.05. Only five LGAs have supply elasticity estimations for non-strata properties greater than 0.5 (Baulkham Hills, 0.64; Camden, 1.05; Liverpool, 0.67; Wollondilly, 0.51; and Wyong, 0.56), and three lowest estimation values occur in 7 LGAs (Lane Cove, 0.06; Mosman, 0.07; Ashfield, 0.08; Kogarah, 0.08; Marrickville, 0.08; Rockdale, 0.08; and Willoughby, 0.08). The patterns from the table can be reinforced by figure 5.3, which shows the supply elasticity estimations for non-strata properties by LGA.

Combined with table 5.2 and figure 5.2, the estimated supply elasticity for strata properties in metropolitan Sydney LGAs can be reported. It is clear that from column 2 table 5.2, 13 out of 43 LGAs have supply elasticity for strata properties greater than unity 1, which means that 30% of LGAs have an elastic housing supply. From figure 5.2, we can see that Baulkham Hills has the highest supply elasticity with a value of 4.45. However, Blue Mountains have the lowest supply elasticity for strata, which is -0.62. Negative elasticity of supply results in an inelastic relationship between quantity supplied and price, indicating that a change in price has no effect on the change in supply. By applying the log annual price and quantity data for strata properties in Blue Mountains, we can obtain figure 5.4 the scatterplot of the prices and quantities of the strata properties in Blue Mountains. The blue dot in figure 5.4 indicates that in the first period, from 1991 to 2002, there is a structure break; the orange dot shows that there is a decrease in both prices and quantities of strata properties in Blue Mountains from 2003 to 2015. Table 5.2 shows that the average supply elasticity estimation for strata properties is 0.83, which is 3.7 times larger than the non-strata properties.

Figure 5.4 Strata Property Prices and Quantities for Blue Mountains



5.4 Cross-section analysis on the determinants of the supply elasticity variation

In the previous sections of this chapter, we modeled and analyzed the housing supply elasticity in the 43 LGAs. In this section, a more inclusive analysis between the supply elasticity and the explanatory variables will be examined.

5.4.1 Scatterplots

To examine the correlation between the explanatory variables and supply elasticity, scatterplots are useful.

Distance to the CBD

The CBD is the commercial and business heart of the metropolitan Sydney, with the higher working opportunities and commercial activities, and it provides a better amenity value for people living within the place. The distance between each LGA and the CBD is measured by the shortest distance between the most significant point in a specific suburb to the CBD, which often synonymous the transportation costs that include time and money spend on travel (Green, Malpezzi and Mayo, 2005). Additionally, a greater distance from the CBD is associated with more potential developable land for future construction. Figure 5.5.1 and 5.5.2 plots the estimated supply elasticity for the strata and Non-strata properties of the LGAs against the distance to the CBD.

Figure 5.5.1 shows the relationship between the supply elasticity of the non-strata property for an LGA and the distance from the LGA to the CBD. From the coefficient, we can see that a positive relationship exists between the two variables, which means that the distance the LGA to the CBD increases by 10 km, and the supply elasticity for non-strata properties will increase by 0.0077.

Figure 5.5.2 shows the relationship between the supply elasticity of the strata property for an LGA and the distance from the LGA to CBD. From table 5.3, it is obvious that unlike the non-strata property, the supply elasticity for strata properties is unrelated to the distance to the CBD.

Figure 5.5.1 Supply Elasticity for Non-strata Properties and the Distance to the CBD

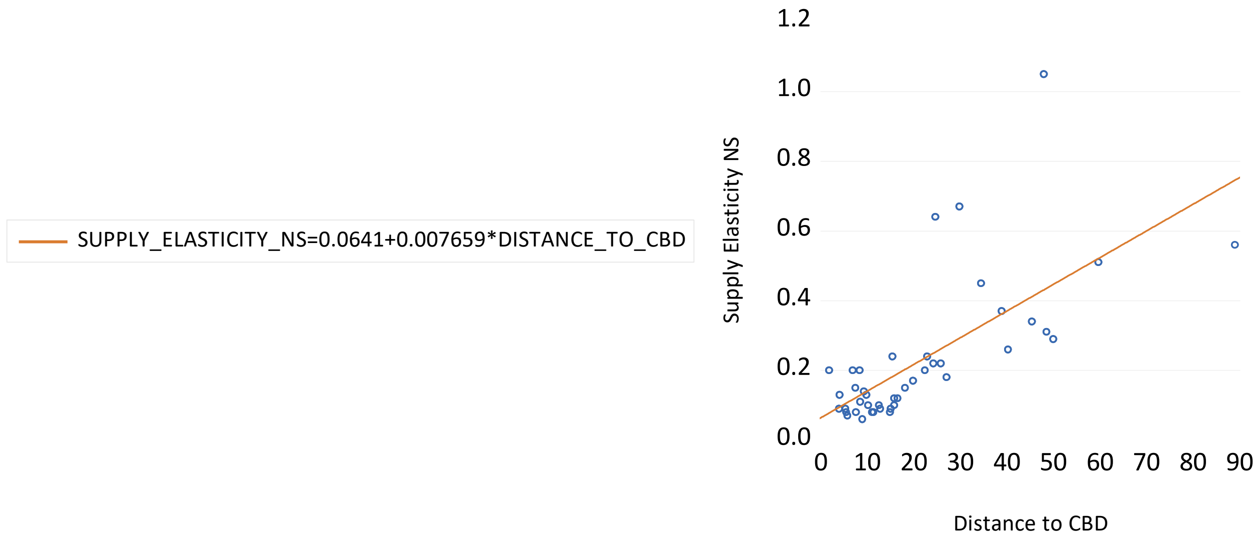


Figure 5.5.2 Supply Elasticity for Strata Properties and the Distance to the CBD

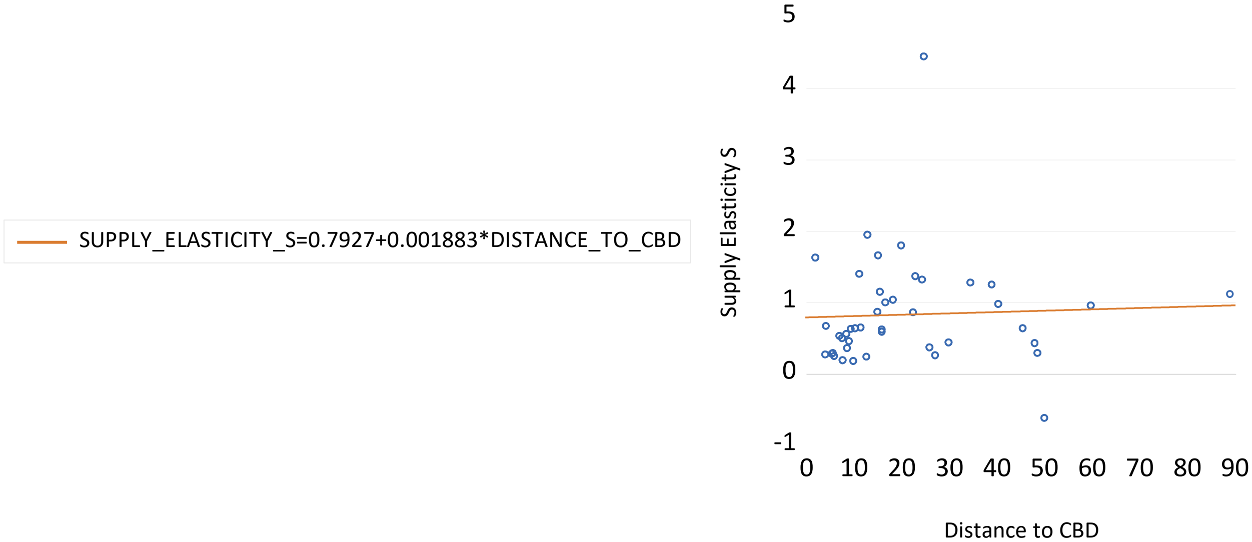


Table 5.3 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Distance to the CBD	0.007659	0.001266	0.0000	0.471689
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Distance to the CBD	0.001883	0.006641	0.7781	0.001958

Development Approval Time

Local governmental regulatory constraints play an important role in supply elasticity estimation. In our thesis, it is measured as the mean time for one development application to be granted by the government official. The time taken for approving one development project directly impacts the construction costs of the developers as the longer time, the more potential costs will be generated. Therefore, the supply elasticity is expected to have a negative relationship with the development approval time.

From figure 5.6.1 and 5.6.2, it is obvious that the mean number of days taken for the development approval is negatively correlated with the supply elasticity for both strata and non-strata properties. The negative sign indicates the higher supply elasticity, the lower time it takes for local government to process a development. From table 5.4, we can see that the correlation for the non-strata property is much higher than the strata properties.

Figure 5.6.1 Supply Elasticity for Non-strata Properties and the Log DA time mean

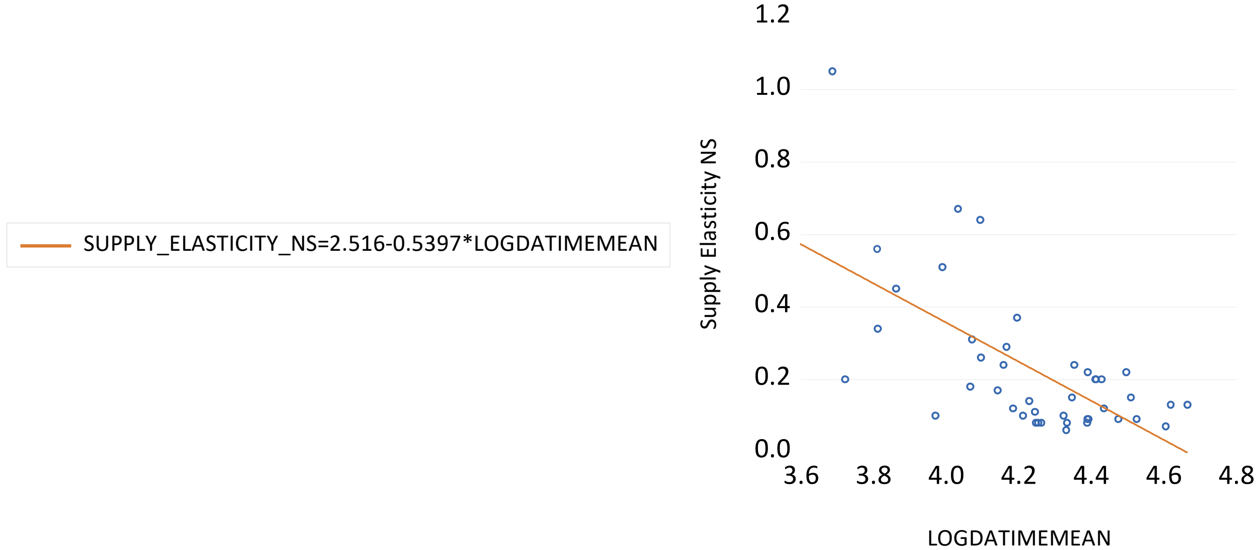


Figure 5.6.2 Supply Elasticity for Strata Properties and the Log DA time mean

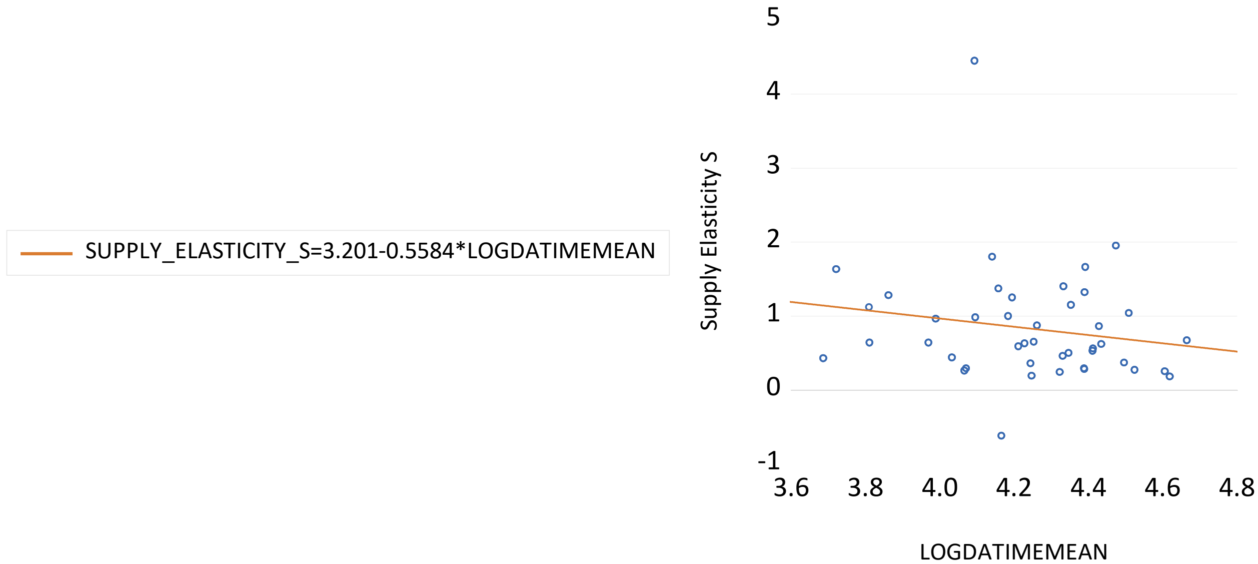


Table 5.4 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Log DA time Mean	-0.539677	0.100800	0.0000	0.411465
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Log DA time Mean	-0.558366	0.493881	0.2648	0.030233

Population density
The population density is determined by two factors: the population and the size of the land in each LGA. As we discussed previously, the further away from the CBD, the larger potential land available for development. Therefore, the supply elasticity and the population density should have a negative relationship.
Figures 5.7.1 and 5.7.2 show the scatterplots of the supply elasticity and the log population. It is clear that both graphs have a downward sloping regression line. From table 5.5, the coefficients of the regression line reinforced the slope of the figures as well as the lower supply elasticity associated with higher population density. Finally, the correlation is significant for the non-strata properties and insignificant for the strata properties.

Figure 5.7.1 Supply Elasticity for Non-strata Properties and the Log Population Density

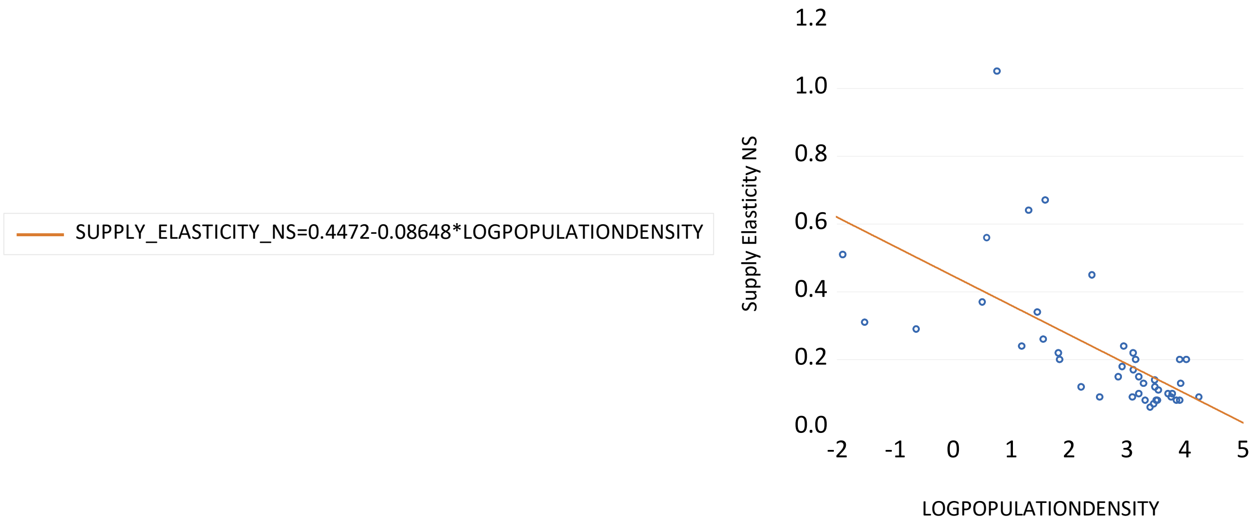


Figure 5.7.2 Supply Elasticity for Strata Properties and the Log Population Density

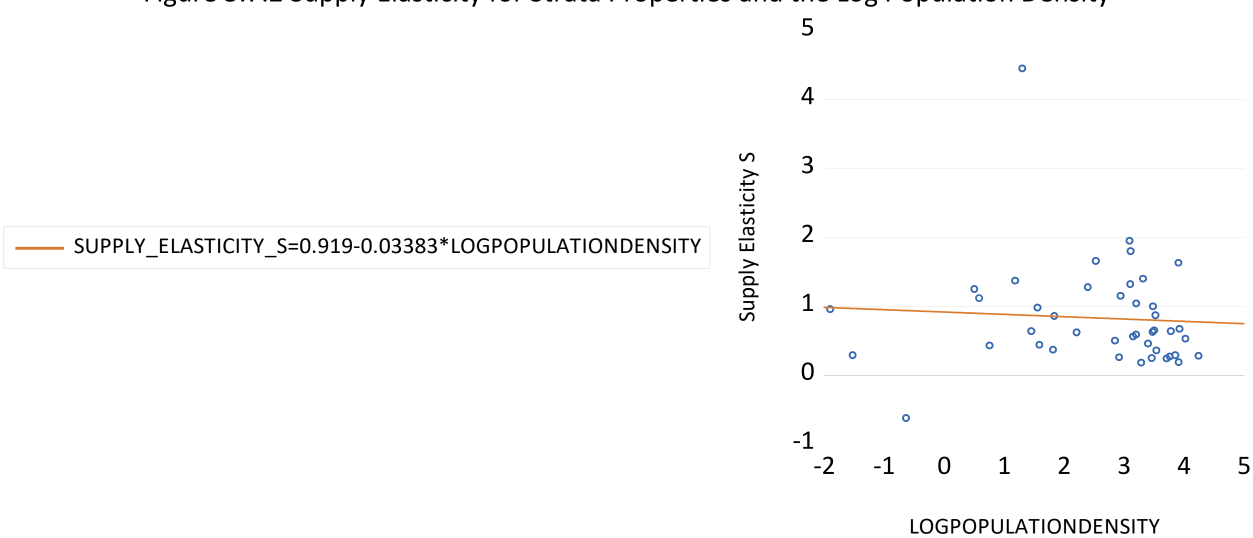


Table 5.5 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Log Population Density	-0.086476	0.016363	0.0000	0.405189
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Log Population Density	-0.033833	0.080809	0.6776	0.004257

Percentage of students enrolled in private school
The high demand for quality education drives private school to be one of the scarcity resources in Australia. The percentage of students enrolled in the private school is determined by the private school density and population density in the specific LGA. Therefore, the percentage of students enrolled in private school and supply elasticity should be negatively correlated.
Figure 5.8.1 and 5.8.2 show the scatterplots of the supply elasticity and the log percentage of students enrolled in private school. It is clear that both graphs have a downward sloping regression line. From table 5.6, the coefficients of the regression line reinforced the slope of the figures as well as the lower supply elasticity associated with higher population density. Finally, the correlation is significant for the nonstrata properties and insignificant for the strata properties.

Figure 5.8.1 Supply elasticity for non-strata properties and the log percentage of students enrolled in private school

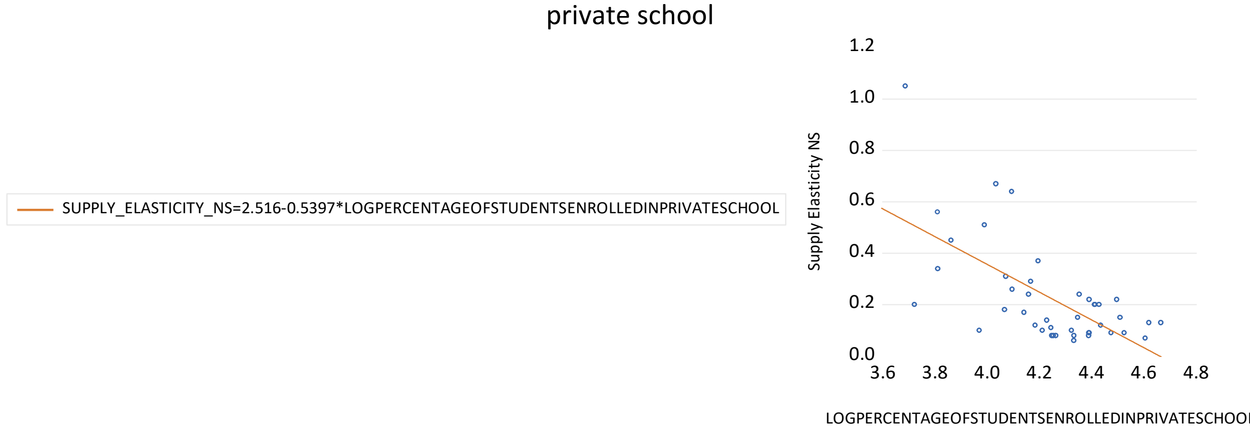


Figure 5.8.2 Supply elasticity for strata properties and the log percentage of students enrolled in private school

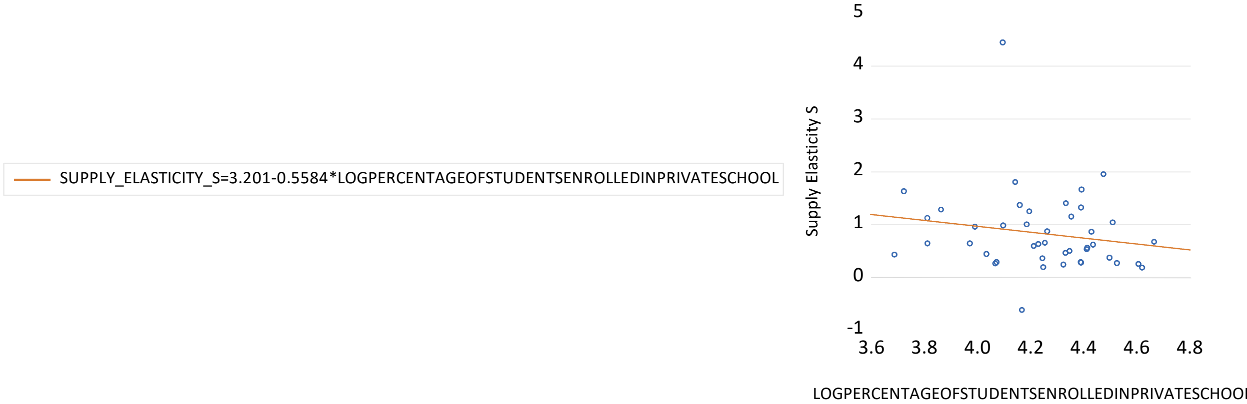


Table 5.6 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Log Percentage of students enrolled in private school	-0.539677	0.100800	0.0000	0.411465
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Log Percentage of students enrolled in private school	-0.558366	0.493881	0.2648	0.030233

Weekly Rental

The weekly rental for residential properties determines the amount of units the owners are willing and able to supply. In this thesis, we begin by investigating the impacts of weekly rental on the supply elasticity for strata and non-strata properties.

Figure 5.9.1 shows the supply elasticity for non-strata properties and the weekly rental. It is obvious that there is a downward sloping regression line, which means the supply elasticity for non-strata properties is higher associated with lower weekly rental.

Figure 5.9.2 plots the supply elasticity for strata properties and the weekly rental. In the graph, we can see that the two variables are positively correlated.

As illustrated by table 5.7, the slope of the two regression lines from figure 5.9.1 and 5.9.2 can be reinforced by the coefficients of the regression lines; however, the supply elasticity for strata properties is unrelated to the rental.

Figure 5.9.1 Supply Elasticity for Non-strata Properties and the Weekly Rental

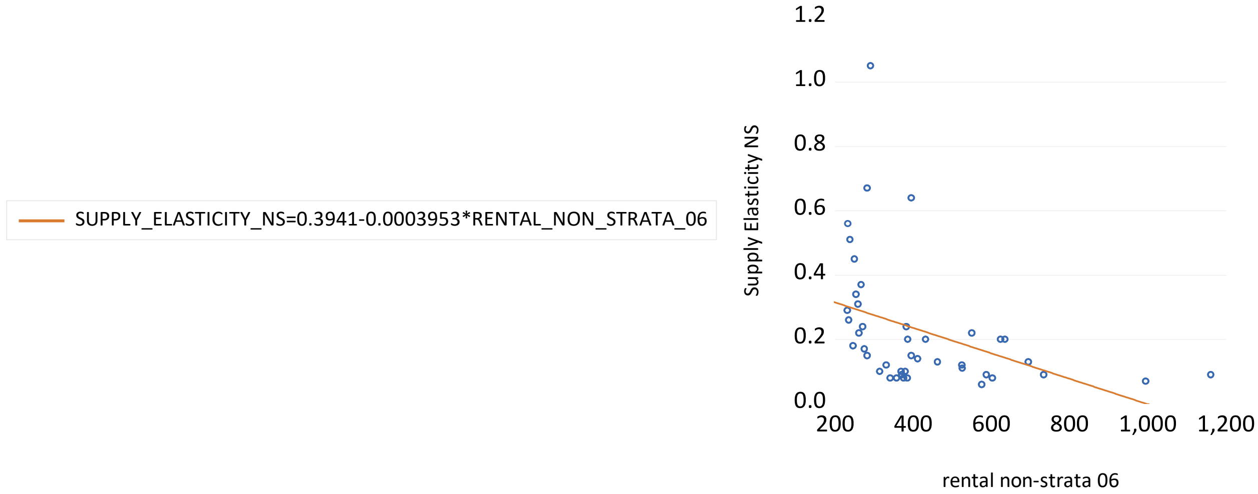


Figure 5.9.2 Supply Elasticity for Strata Properties and the Weekly Rental

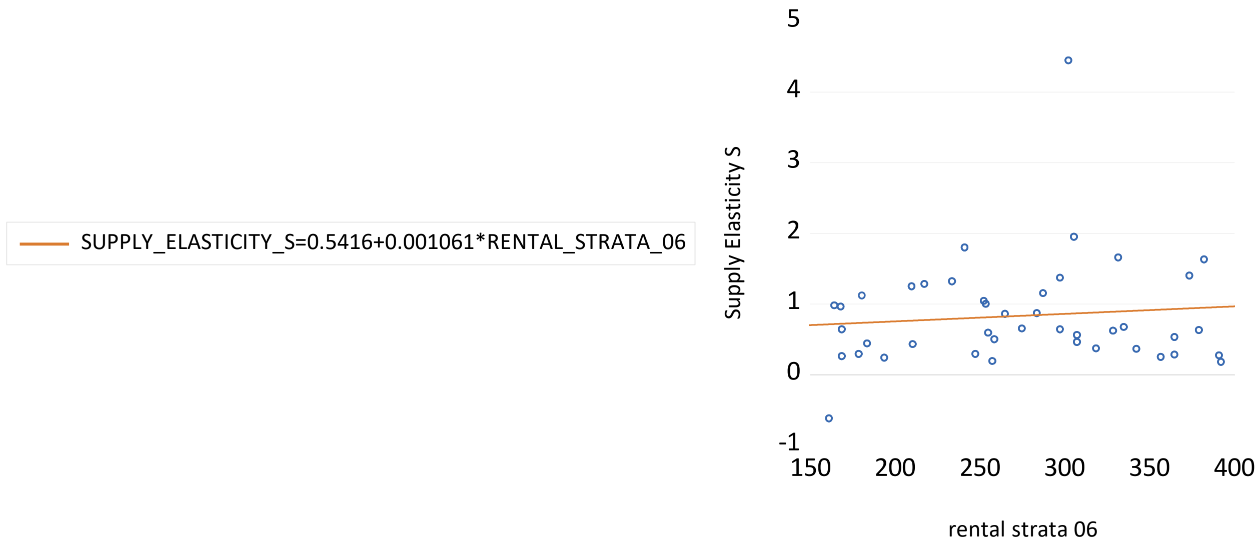


Table 5.7 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Weekly Rental	-0.000395	0.000143	0.0084	0.157452
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Weekly Rental	0.001061	0.001674	0.5296	0.009710

Crime Rate
The crime rate is measured as the percentage of total crime divided by the population in a specific LGA. Figure 5.10.1 and 5.10.2 plot the supply elasticity for strata and non-strata properties with respect to the log crime rate in the 43 LGAs. It is clear that both of the graphs have upward slopes with can also be seen in the coefficients terms of table 5.8. However, the supply elasticity of both types of dwelling is not significantly correlated with the crime rate.

Figure 5.10.1 Supply Elasticity for Nonstrata Properties and the Log Crime Rate

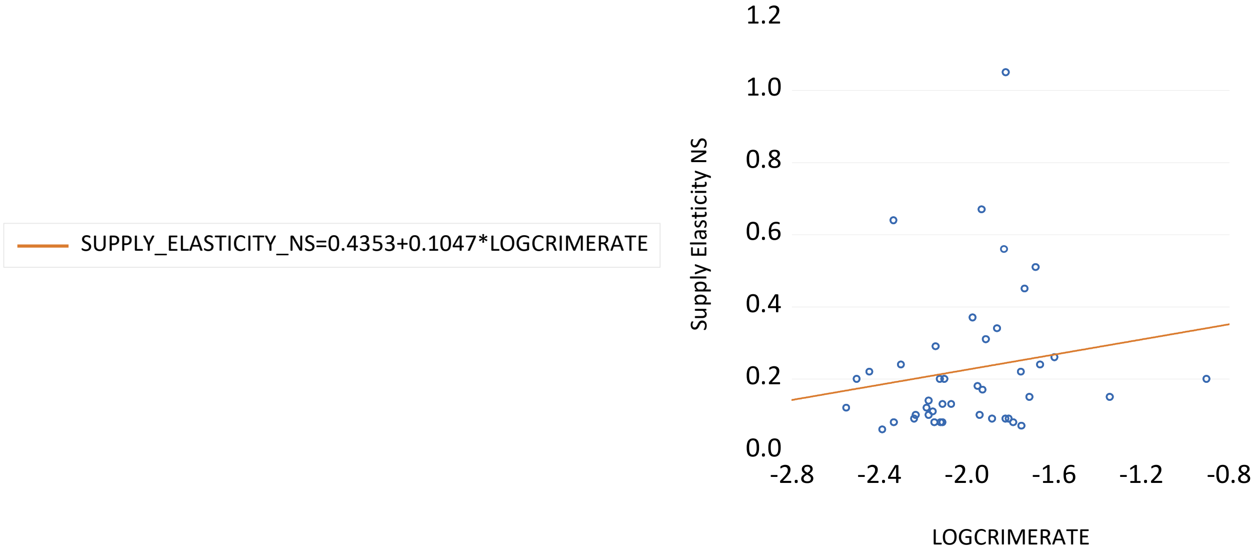


Figure 5.10.2 Supply Elasticity for Strata Properties and the Crime Rate

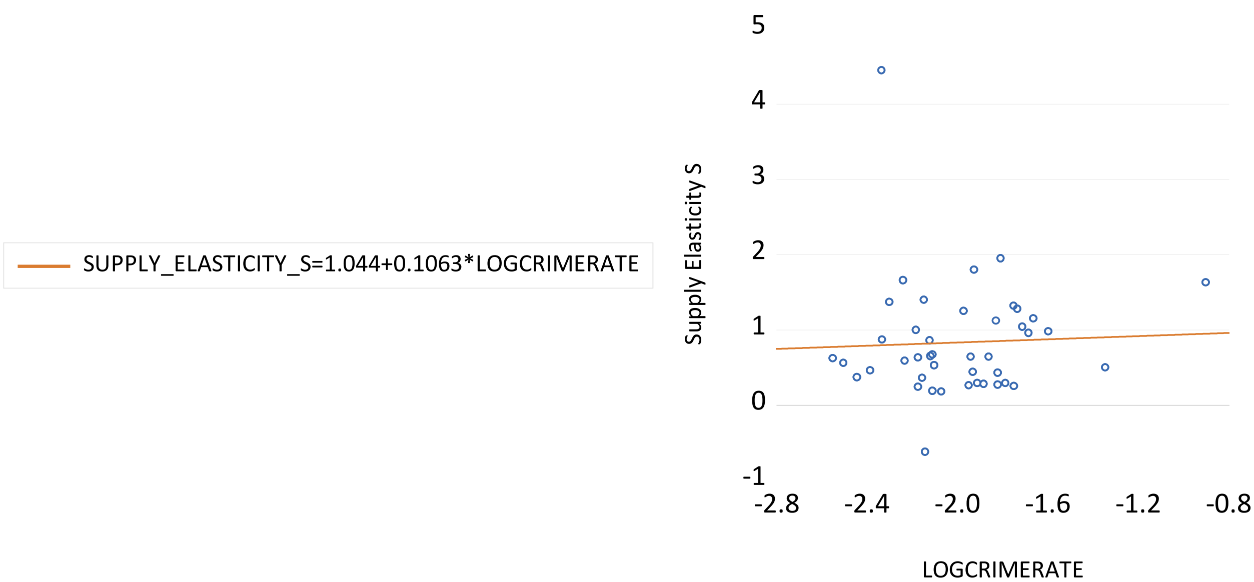


Table 5.8 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Log Crime Rate	0.104729	0.099459	0.2985	0.026331
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Log Crime Rate	0.106334	0.384368	0.7834	0.001863

Geographic Factors

From chapter 4, we have listed the geographic factors and the relative data sources we are going to use in this thesis. The data source based on the ASGC 2006, the degree of land availability in each LGA will be analyzed with respect to the supply elasticity for strata and non-strata properties.

Figure 5.11.1, 5.12.1, 5.13.1, and 5.14.1 indicate that the correlation between supply elasticity for non-strata properties and Geo1, Geo3 and Geo4 is significant at a 10 percent significance level. On the other hand, for the strata properties. Figure 5.11.2, 5.12.2, 5.13.2, and 5.14.2 indicate that only Geo4 is related to the supply elasticity at a 10 percent significance level.

Based on the figures for non-strata properties below, it is obvious that only Geo3 has a negative relationship with supply elasticity. For strata properties, only Geo4 has a positive relationship with the supply elasticity.

The scatterplots for non-strata properties indicated that the higher supply elasticity is associated with a higher land availability, and the correlation for non-strata properties is much more significant than strata properties.

Figure 5.11.1 Supply Elasticity for Non-strata Properties and Geo1

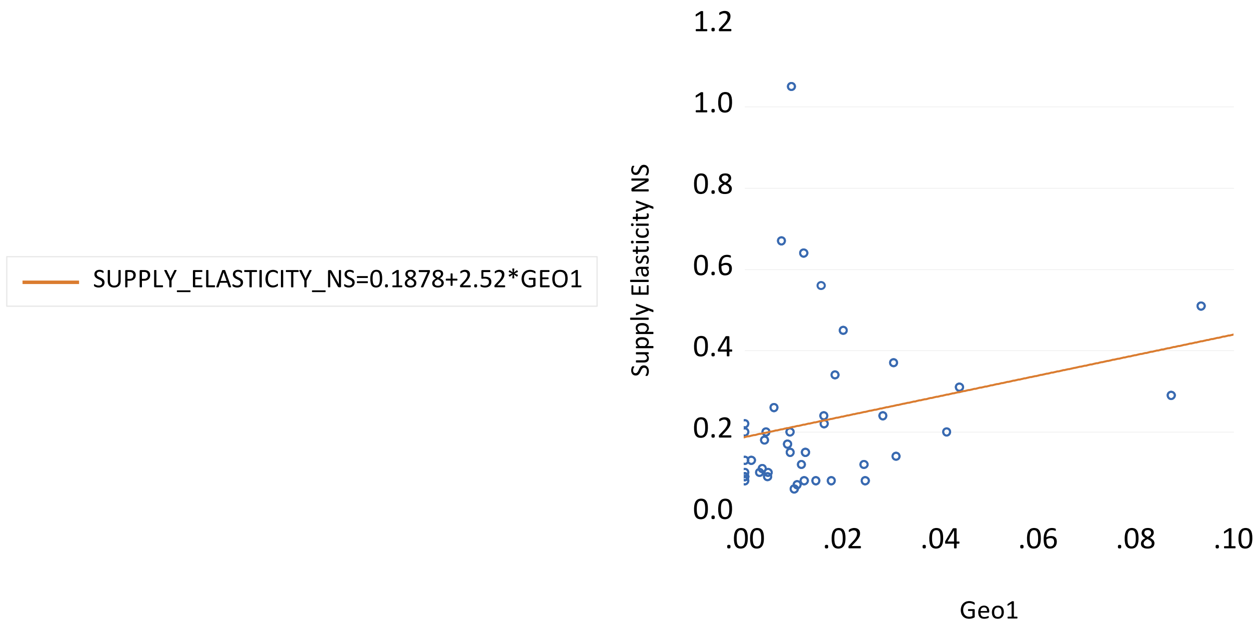


Figure 5.11.2 Supply Elasticity for Strata Properties and Geo1

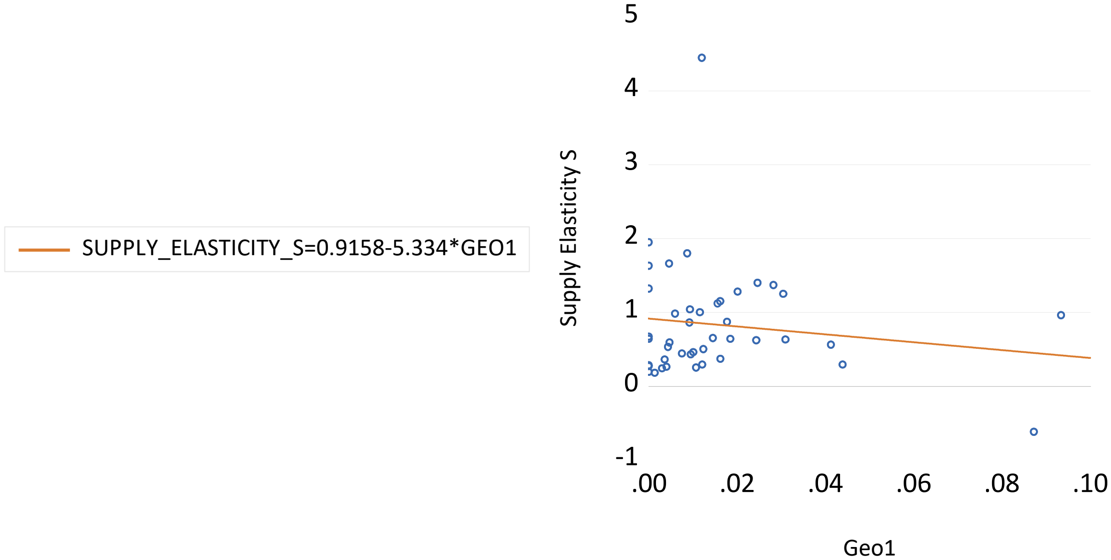


Table 5.9 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Geo1	2.519948	1.517057	0.1043	0.063054
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Geo1	-5.334367	5.923857	0.3731	0.019394

Geo_1 measures the amount of land which is unable for housing development activities, from table 5.9 we can see that there is a positive relationship between supply elasticity for non-strata property and Geo_1 and a negative relationship between supply elasticity for strata property and Geo_1. Under a 10% significance level, the supply elasticity for non-strata property is directly affected by the amount of land which is unable for housing development activities, which means that 1 unit increase in Geo_1 will result a 2.52 times supply elasticity increase.

Figure 5.12.1 Supply Elasticity for Non-strata Properties and Geo2

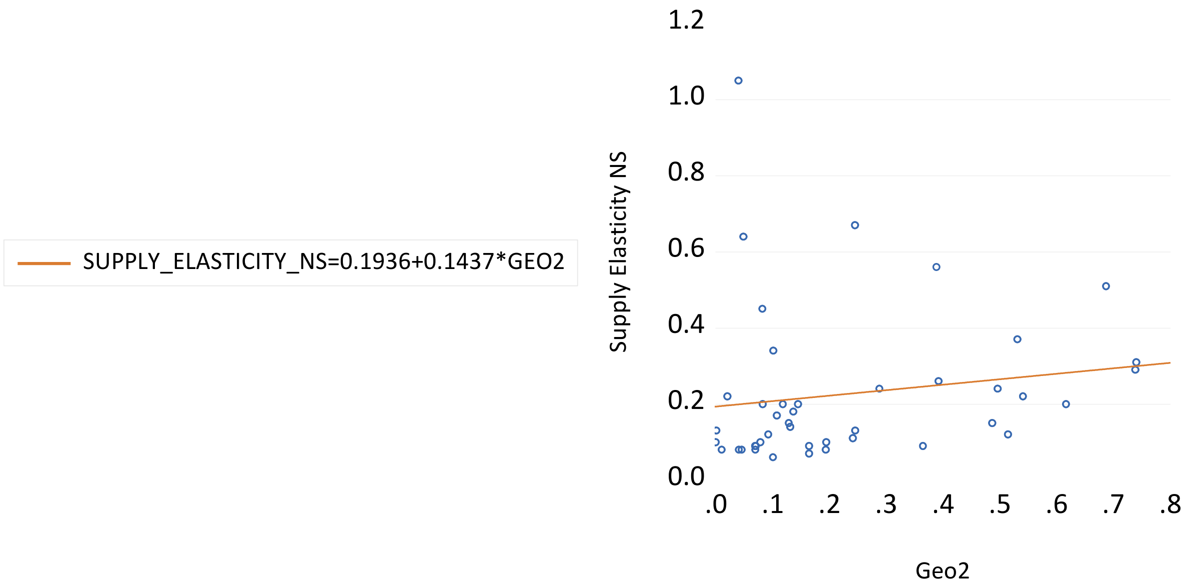


Figure 5.12.2 Supply Elasticity for Strata Properties and Geo2

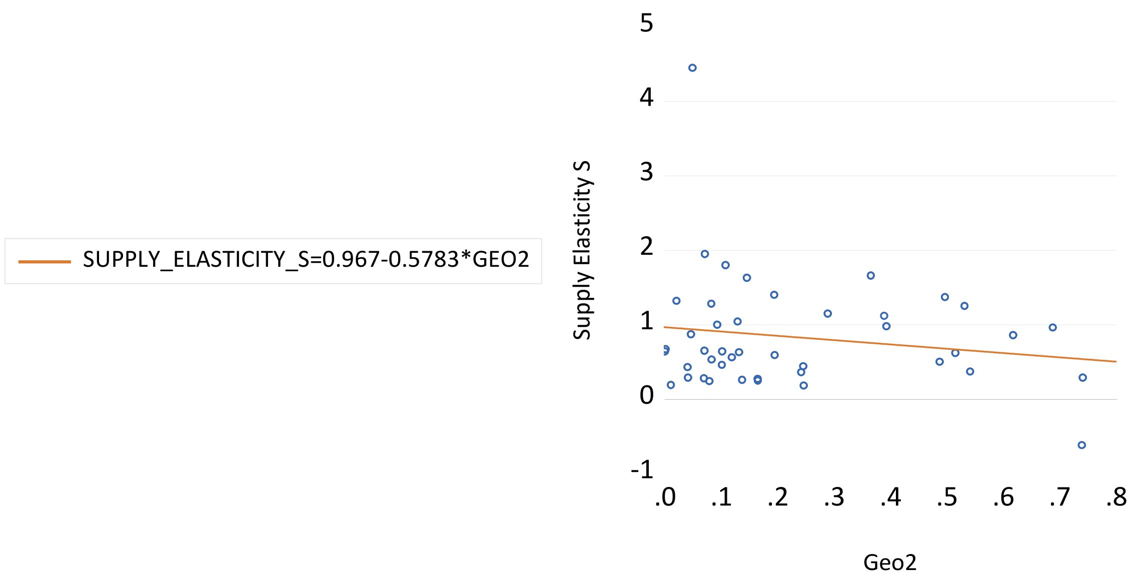


Table 5.10 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Geo2	0.143691	0.143445	0.3224	0.023889
Estimated Supply Elasticity for Strata Property				

Variable	Coefficient	Std. Error	Prob.	R-squared
Geo2	-0.578287	0.546769	0.2964	0.026559

Geo_2 shows the amount of land local government specifically designed for future public facilities purpose plus the amount land defined by Geo_1, from table 5.10 we can see that there is a positive relationship between supply elasticity for non-strata property and Geo_2 and a negative relationship between supply elasticity for strata property and Geo_2. Under a 10% significance level, the supply elasticity for the two types of dwellings will not be correlated with the changes in Geo_2.

Figure 5.13.1 Supply Elasticity for Non-strata Properties and Geo3

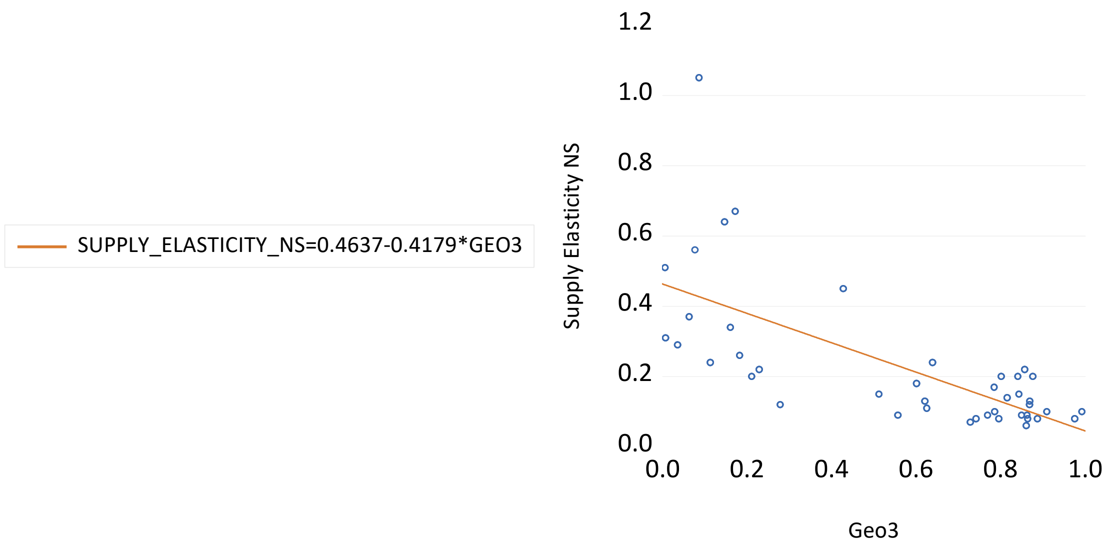


Figure 5.13.2 Supply Elasticity for Strata Properties and Geo3

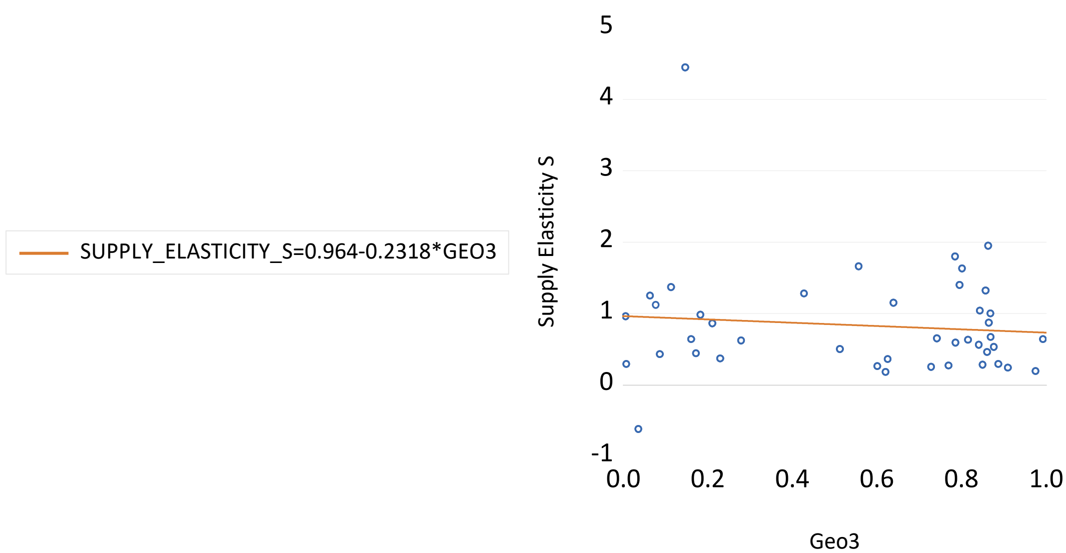


Table 5.11 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Geo3	-0.417931	0.068420	0.0000	0.476450
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Geo3	-0.231764	0.359106	0.5223	0.010057

Geo_3 is defined by Australian Road Rules as the meaning of built-up area, from their definition, Geo_3 measures the amount land which LGA treated as built-up area, from table 5.11 we can see that there is a negative relationship between supply elasticity for both types of the dwellings and Geo_3. Under a 10% significance level, the supply elasticity for non-strata property is directly affected by the built-up area, which means that 1 unit increase in Geo_3 will result a 0.42 times supply elasticity decrease.

Figure 5.14.1 Supply Elasticity for Non-strata Properties and Geo4

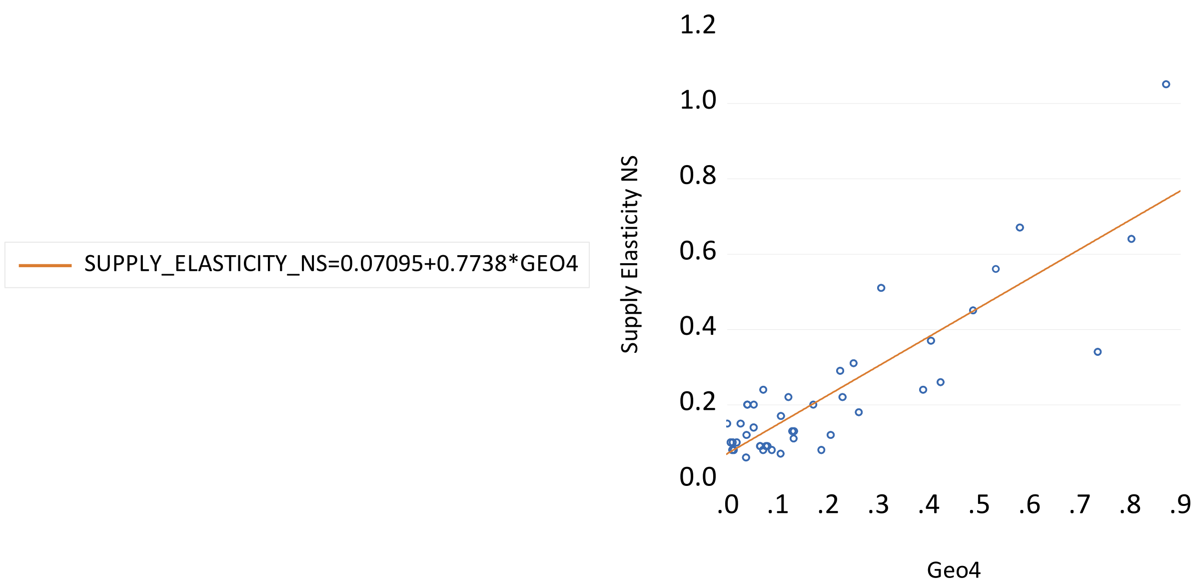


Figure 5.14.2 Supply Elasticity for Strata Properties and Geo4

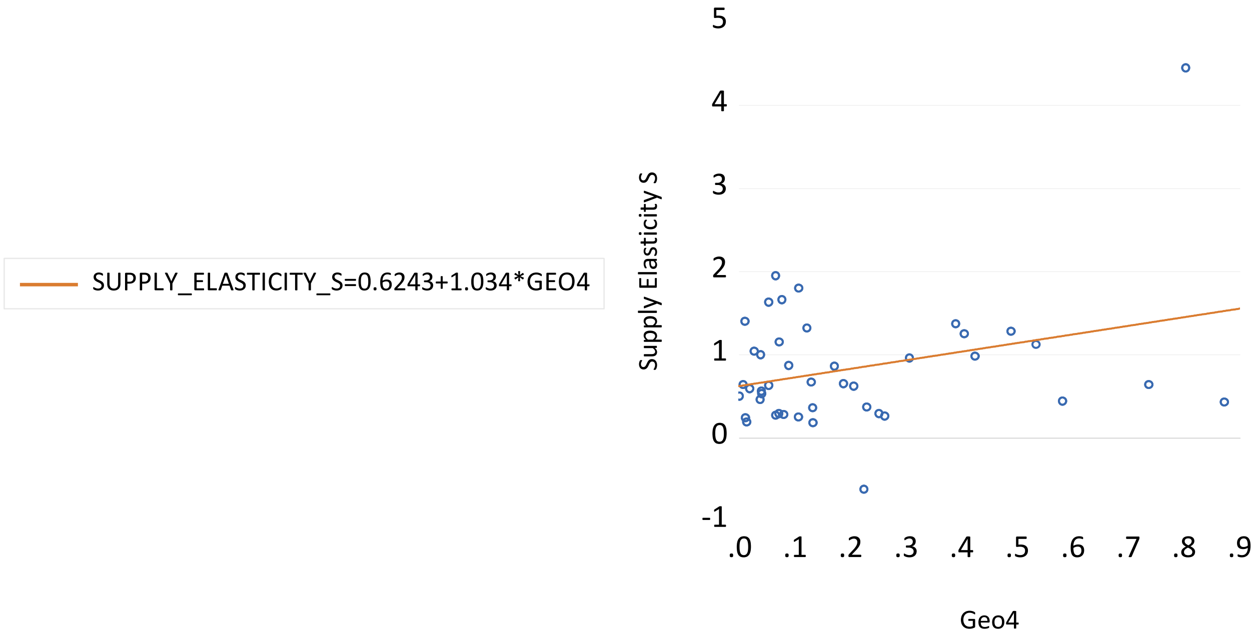


Table 5.12 Estimation Results

Estimated Supply Elasticity for Non-strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Geo4	0.773813	0.069119	0.0000	0.753512
Estimated Supply Elasticity for Strata Property				
Variable	Coefficient	Std. Error	Prob.	R-squared
Geo4	1.034086	0.506253	0.0476	0.092365

Geo_4 is the sum of Geo_1, Geo_2 and Geo_3, from table 5.11 we can see that there is a positive relationship between supply elasticity for both types of the dwellings and Geo_4. Under a 10% significance level, the supply elasticity for both non-strata and strata property are directly affected by Geo_4, which means that 1 unit increase in Geo_4 will result a 0.77 times and 1.03 time supply elasticity increases for non-strata and strata property.

As discussed above, we can conclude that the four geographic factors have mostly positive effects on the supply elasticity of non-strata property, which means the more restriction on land the higher supply elasticity resulted. Only exemption from Geo_3, which is the built up land has a negative relation between the supply elasticity of non-strata property, due to the fact that it is hard for developers to acquire land for the purpose of building non-strata properties, in terms of funding and regulatory pressures. From the supply elasticity of strata property, we can see that the only significant result is from Geo_4, which is the sum of Geo_1, Geo_2 and Geo_3. The finding indicated that the less land available for development, the higher supply elasticity will be.

5.4.2 Brief summary

In section 5.4, we used the scatterplots and linear regression to see the relationship between supply elasticity for strata and non-strata properties to the explanatory variables we mentioned in the previous chapter. Table 5.13 provides a brief summary of the information provided above, as we can see, most of the explanatory variables are not correlated with the supply elasticity of strata properties; thus, in the next section, we focus primarily on the supply elasticity for non-strata properties and the explanatory variables.

Table 5.13 Summarize Information

Estimated Supply Elasticity for Non-strata Property		
Variable	Sign of the correlation	Significance of the relationship
Distance to CBD	+	Significant (10%)
Log DA time Mean	-	Significant (10%)
Log Population Density	-	Significant (10%)
Log Percentage of students enrolled in private school	-	Significant (10%)
Weekly Rental	-	Significant (10%)
Log Crime Rate	+	Not Correlated (10%)
Geo1	+	Significant (10%)
Geo2	+	Not Correlated (10%)
Geo3	-	Significant (10%)
Geo4	+	Significant (10%)
Estimated Supply Elasticity for Strata Property		
Variable	Sign of the correlation	Significance of the relationship
Distance to CBD	+	Not Correlated (10%)
Log DA time Mean	-	Not Correlated (10%)
Log Population Density	-	Not Correlated (10%)
Log Percentage of students enrolled in private school	-	Not Correlated (10%)
Weekly Rental	+	Not Correlated (10%)
Log Crime Rate	+	Not Correlated (10%)
Geo1	-	Not Correlated (10%)
Geo2	-	Not Correlated (10%)
Geo3	-	Not Correlated (10%)
Geo4	+	Significant (10%)

5.5 Determinants of supply elasticity

From the results in section 5.4, we could construct a set of linear models with respect to the explanatory variables and the supply elasticity for strata and non-strata properties. The explanatory variables include distance to the CBD, the log DA time mean, the log population density, the log percentage of students enrolled in private school, weekly rental, log crime rate and geographic factors.

The results for linear regression models for strata and non-strata properties are shown in tables 5.14 and 5.15. In both sets of models a and b, we keep explanatory variables: distance to the CBD, log population density, log percentage of students enrolled in private school, weekly rental and log crime rate as fixed. We change the geographic variables from Geo1 to Geo4 from models a1 to a4 and b1 to b4. In models a5 and b5, we change the development approval time from mean to median. By doing so, in table 5.14 from model a1 to a5, the results can represent 60 to 80 percent of the variations. It is obvious that all geographic variables have a significant relationship with supply elasticity.

In model a1, Geo1, DA time mean and log population density are the three variables correlated with estimated supply elasticity for non-strata properties. From chapter 4 preliminary data analysis, Geo1 is defined as the amount of undeveloped land introduced by Saiz (2010). By looking at the sign of each variable, all three of the explanatory variables have negative effects on the supply elasticity for non-strata properties in metropolitan Sydney.

Based on model a2, Geo2 and log population density correlated with supply elasticity at a 5% significance level. In this model, the availability of land was more restricted than in Geo1 when certain types of reserved land were included, so it has a smaller negative effect on the supply elasticity.

In the third model in table 5.14, the two variables correlated with the supply elasticity are Geo3 and DA time mean. Geo3 measures the amount of land defined as built-up areas, which could be regarded as expensive and hard for future development. It is clear that both variables have a negative effect on the supply elasticity estimations for non-strata properties.

In models a4 and a5, a positive correlation exists between Geo4 and supply elasticity for non-strata properties. Geo4 measures the amount of unavailable land that is not available for development. In model a5, we used median DA time instead of the mean DA time.

As discussed above, for non-strata properties, the geographic factors (degree of land unavailability), development approval time, and population density have the most significant effect on supply elasticity.

Another important observation from table 5.15 is that the relation between supply elasticity for strata properties and the explanatory variables. For the strata properties, the geographic factors, development approval time and the weekly rental play a significant role in changing the supply elasticity.

Table 5.14 Linear Regression Model for Non-strata Properties

Dependent Variable: Supply Elasticity for Non-strata Properties					
Independent Variables	Model a1	Model a2	Model a3	Model a4	Model a5
Geo1	-3.3739 (1.6324)	-	-	-	-
Geo2	-	-0.6022 (0.1615)	-	-	-
Geo3	-	-	-0.3402 (0.1539)	-	-
Geo4	-	-	-	0.6300 (0.1014)	0.6698 (0.1006)
Distance to CBD	0.0019 (0.0026)	0.0015 (0.0023)	0.0025 (0.0025)	0.0002 (0.0019)	0.0006 (0.0020)
DA time Mean	-0.0050 (0.0020)	-0.0023 (0.0019)	-0.0046 (0.0020)	-0.0013 (0.0016)	-
DA time Median	-	-	-	-	0.0003 (0.0018)
Log Population Density	-0.0837 (0.0348)	-0.1348 (0.0354)	0.0264 (0.0393)	-0.0207 (0.0197)	-0.0177 (0.0201)
Log Percentage of students enrolled in private school	-0.0221 (0.0263)	-0.0067 (0.0241)	-0.0297 (0.0260)	-0.0106 (0.0193)	-0.0039 (0.0188)
Weekly Rental	0.0002 (0.0002)	0.0001 (0.0001)	0.0001 (0.0002)	0.0000 (0.0001)	0.0000 (0.0001)
Log Crime Rate	-0.0092 (0.0730)	0.0474 (0.0655)	0.0186 (0.0718)	0.0638 (0.0535)	0.0781 (0.0511)
Constant	0.6919 (0.2319)	0.8655 (0.2153)	0.5802 (0.2178)	0.3430 (0.1623)	0.2704 (0.1778)
$\overline{R^2}$	0.6157	0.6914	0.6216	0.7950	0.7911

Notes: The numbers in parentheses are the Standard Error.

Table 5.15 Linear Regression Model for Strata Properties

Dependent Variable: Supply Elasticity for Strata Properties					
Independent Variables	Model b1	Model b2	Model b3	Model b4	Model b5
Geo1	-16.0545 (8.6650)	-	-	-	-
Geo2	-	-1.9344 (0.948)	-	-	-
Geo3	-	-	-0.3157 (0.8621)	-	-
Geo4	-	-	-	1.3650 (0.7269)	1.2204 (0.7055)
Distance to CBD	-0.0079 (0.014)	-0.0068 (0.014)	-0.0028 (0.0148)	-0.0091 (0.0145)	-0.0120 (0.0142)
DA time Mean	-0.0196 (0.009)	-0.0117 (0.010)	-0.0196 (0.0099)	-0.0130 (0.0101)	-
DA time Median	-	-	-	-	-0.0241 (0.0125)
Log Population Density	-0.3278 (0.185)	-0.4220 (0.208)	-0.0484 (0.2211)	-0.0712 (0.1437)	-0.1036 (0.1418)
Log Percentage of students enrolled in private school	-0.2367 (0.1366)	-0.2018 (0.1375)	-0.2592 (0.1426)	-0.2307 (0.1367)	-0.2442 (0.1319)
Weekly Rental	0.0057 (0.0026)	0.0060 (0.0025)	0.0056 (0.0027)	0.0051 (0.0026)	0.0072 (0.0029)
Log Crime Rate	-0.1882 (0.3871)	0.0242 (0.3841)	-0.0853 (0.4014)	0.0137 (0.3871)	0.1793 (0.3581)
Constant	1.2619 (1.388)	1.4857 (1.4003)	0.5634 (1.4028)	0.1910 (1.3301)	0.4704 (1.3029)
$\overline{R^2}$	0.2547	0.2686	0.1847	0.2565	0.2959

Notes: The numbers in parentheses are the Standard Error.

5.6 Conclusions

In this chapter, we detailed the model development process for the supply elasticity estimation and then analyzed the quality of instruments used in the modeling process. By finding the supply elasticity estimations for different types of dwellings in the 43 LGAs, we then apply a cross-sectional analysis to find the determinates of the supply elasticity. The results in this chapter indicate that for the majority of the LGAs, the supply elasticity for strata properties is larger than the non-strata properties. The development approval time and geographic factors play a significant role in changing the supply elasticity for both types of dwellings.

Note: Since we generate the dependant variable in our model, standard errors may be conservative. Further analysis may be conducted in the future to investigate this possibility.

Chapter 6 Conclusion

6.1 Introduction

This thesis provides a comprehensive analysis of the elasticity estimation in metropolitan Sydney at a local government level. Chapter 2 provides a detailed discussion about the fundamental variables used by previous studies in modeling housing supply elasticity. Chapter 3 discusses the price movements of dwellings, presented the dwelling stocks and the development approval in each LGA. Chapter 4 provides detailed information about the sources of data for the variables mentioned in chapter 2 and presents a preliminary analysis of the variables. Based on the findings from chapters 2, 3 and 4, the results can be applied to the following model construction and supply elasticity estimation chapter.

In chapter 5, the model for supply elasticity estimation has been established. The estimation results for strata and non-strata properties have been stated, and the explanatory factors that affect the supply elasticity in each LGA have been investigated.

In the subsequent sections, we will discuss the findings from this thesis. The rest of this chapter will be organized as follows: section 6.2 summarizes the findings from this paper; section 6.3 provides a policy implication for the findings of this study; section 6.4 discusses the limitations of this study and provides possible directions for future research on this topic.

6.2 Summary of findings

This article comprises three main parts:

- The development of the supply elasticity estimation model for metropolitan Sydney housing market at a local government level
- Estimate the supply elasticity for strata and non-strata properties across the 43 LGAs
- Apply different explanatory factors to run cross-section analysis on the determinants of the supply elasticity variation

Supply elasticity for 43 LGAs

This thesis uses annual data from 1991 to 2015 to estimate the supply elasticity for strata and non-strata properties in the 43 local government areas. The supply of non-strata properties is inelastic for the 42 LGAs; only Camden has a value greater than 1. Based on the geographic local, Camden belongs to the outer ring, with high stocks and increasing yearly development approvals, resulting in an elastic supply in the non-strata properties. In contrast, 13 out of 43 LGAs have a greater than unity supply elasticity for the strata properties. The supply elasticity for strata properties on average is 3.7 times larger than the non-strata properties. Across the 43 LGAs, the average supply elasticity for strata properties is 0.83 and 0.23 for non-strata properties. The highest supply elasticity for strata occurs in Baulkham Hills, and the lowest supply elasticity occurs in Blue Mountains. With a structure break, the Blue Mountains not only have the lowest supply elasticity in strata property but also enjoys a negative value, which is -0.62. On the other hand, for the non-strata properties, Camden has the highest supply elasticity, with a value of 1.05 being the only local government area with an elastic supply for the non-strata properties. Land

Cove with a value of 0.06 for the supply elasticity ranks the lowest in the 43 LGAs for the non-strata properties.

Cross-section analysis on the determinants of the supply elasticity variation

We examined supply elasticity with explanatory variables such as distance to CBD, development approval time, population density, percentage of students enrolled in private school, weekly rental, crime rate and geographic factors that measured the degree of land unavailability.

The analysis presented in chapter 5 identified the relationships between supply elasticity and the seven variables using the scatterplot and linear regression model. Based on the analysis results in table 5.13, all of the variables are not significantly correlated with the supply elasticity for strata properties at a 10 percent significance level. For the non-strata properties, the results can be presented as follows.

First, there is a positive correlation between the distance to CBD. The increase in distance between the CBD and LGAs can increase the amount of land. The total amount of land is restricted within the CBD, which makes it harder for developers to acquire the land and requires more funds to start the project. The land is scarce in the LGAs closer to the CBD, and it is less efficient to allocate the land for non-strata property development use. There is more available lands farther away from CBDs, thus increasing the supply for non-strata properties.

Second, there is a negative relationship between the development approval time. As Malpezzi and Mayo (1997) found, the higher restriction on government regulations will increase the development costs that reduce the supply of houses. Under this circumstance, the development approval time is determined by the local government on land planning and usage. The stricter the local government regulations, the longer time it going to take for one project to be approved, which leads to higher costs and harder to fund. Eventually, the developer is unwilling to supply.

Third, Saiz (2010) and Paciorek (2013) used U.S. data to indicate that a higher population and population density in a specific city will decrease the supply elasticity. The result is easy to understand, as it is less efficient to allocate non-strata properties where the population density is high, which will not be able to satisfy the requirement of the housing market.

Fourth, similar to the population density, private education in LGAs can be regarded as a scarcity goods. The amount of schools and the capability of school in each LGA is restricted, and it is inefficient to allocate the non-strata properties in LGAs with abounded education resources.

Fifth, there is a negative relationship between the supply elasticity for non-strata properties and the weekly rental. By analyzing the rental data for the 43 LGAs, the higher weekly rental tends to occur in the inner ring and middle ring, which is close to the CBD of Sydney. As we mentioned above, areas closer to the CBD have less land that is available for non-strata property development. With the limitation on the number of stocks supplied, a higher rental will be generated, which leads to a negative correlation between the weekly rental and supply elasticity for non-strata properties.

Sixth, the crime rate is measured as a percentage of the total amount of crime occurring in the LGA divided by the number of populations in that LGA. Lee and Klimova (2014) studied the relationship between the nearby murder and housing prices and rents in Sydney. From their study, the crime happened within 0.2 miles of the homes will lead to a 3.9% decrease one year after the murder and has no effect on the rent. Under a local government level study, their results will be strict for us to apply. Based on the scatterplots, crime rate is not significantly correlated with the supply of non-strata properties.

Last but not least is the geographic factors (Geo1, Geo2, Geo3 and Geo4), which measured the different degrees of land unavailable for development. As the results indicated, the built-up areas and the reserved lands are correlated with the inelastic supply of non-strata properties. The topographic futures mentioned by Geo1 do not have a significant effect on the supply elasticity.

6.3 Policy implication

The findings of this study have some important implications for policymakers regarding decisions on the local governmental level. First, the long-run trends for real and nominal prices of dwelling implies future continuous growth in the housing market in metropolitan Sydney. Thus, housing affordability will be another issue for the local government to consider.

Second, the results from supply elasticity estimations suggest that under strict land use regulations in metropolitan Sydney, the land price has increased, which leads to an increase in house prices. The inadequate between dwelling supplied and demanded caused by the series of policies needed to be solved by new development strategies.

6.4 Limitation of this study and future research

The main limitation of this study is the availability of data sources. For the dwelling stocks, we have only five-year data available, which is from the census reports. Using the annual approval data to proxy the amount of dwelling each year will cause the differences between the actual data each year. The income data for each LGA are also limited.

Another limitation of this study is that it focused on only the 43 LGAs in metropolitan Sydney, which is a small part of the state of New South Wales.

Future studies can extend the research by:

1. Proxy the annual stocks by considering the dwelling completions each year instead of the dwelling approved.

2. Consider more explanatory variables that determine the supply elasticities.

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Appendix

F Statistic (Table E)

Table entry for p is the critical value F^* with probability p lying to its right.

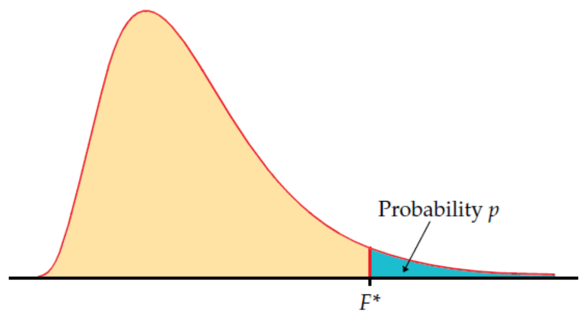

TABLE E

F critical values

Degrees of freedom in the denominator	p	1	2	3	4	5	6	7	8	9
		Degrees of freedom in the numerator								
1	.100	39.86	49.50	53.59	55.83	57.24	58.20	58.91	59.44	59.86
	.050	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54
	.025	647.79	799.50	864.16	899.58	921.85	937.11	948.22	956.66	963.28
	.010	4052.2	4999.5	5403.4	5624.6	5763.6	5859.0	5928.4	5981.1	6022.5
	.001	405284	500000	540379	562500	576405	585937	592873	598144	602284
2	.100	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38
	.050	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38
	.025	38.51	39.00	39.17	39.25	39.30	39.33	39.36	39.37	39.39
	.010	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39
	.001	998.50	999.00	999.17	999.25	999.30	999.33	999.36	999.37	999.39
3	.100	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24
	.050	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
	.025	17.44	16.04	15.44	15.10	14.88	14.73	14.62	14.54	14.47
	.010	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35
	.001	167.03	148.50	141.11	137.10	134.58	132.85	131.58	130.62	129.86
4	.100	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94
	.050	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
	.025	12.22	10.65	9.98	9.60	9.36	9.20	9.07	8.98	8.90
	.010	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66
	.001	74.14	61.25	56.18	53.44	51.71	50.53	49.66	49.00	48.47
5	.100	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32
	.050	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
	.025	10.01	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68
	.010	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16
	.001	47.18	37.12	33.20	31.09	29.75	28.83	28.16	27.65	27.24
6	.100	3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96
	.050	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10
	.025	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52
	.010	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98
	.001	35.51	27.00	23.70	21.92	20.80	20.03	19.46	19.03	18.69
7	.100	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72
	.050	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
	.025	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82
	.010	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72
	.001	29.25	21.69	18.77	17.20	16.21	15.52	15.02	14.63	14.33

Table entry for p is the critical value F^* with probability p lying to its right.

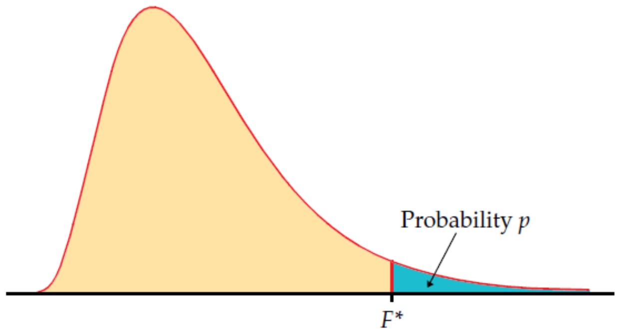

TABLE E

F critical values (continued)

Degrees of freedom in the numerator										
10	12	15	20	25	30	40	50	60	120	1000
60.19	60.71	61.22	61.74	62.05	62.26	62.53	62.69	62.79	63.06	63.30
241.88	243.91	245.95	248.01	249.26	250.10	251.14	251.77	252.20	253.25	254.19
968.63	976.71	984.87	993.10	998.08	1001.4	1005.6	1008.1	1009.8	1014.0	1017.7
6055.8	6106.3	6157.3	6208.7	6239.8	6260.6	6286.8	6302.5	6313.0	6339.4	6362.7
605621	610668	615764	620908	624017	626099	628712	630285	631337	633972	636301
9.39	9.41	9.42	9.44	9.45	9.46	9.47	9.47	9.47	9.48	9.49
19.40	19.41	19.43	19.45	19.46	19.46	19.47	19.48	19.48	19.49	19.49
39.40	39.41	39.43	39.45	39.46	39.46	39.47	39.48	39.48	39.49	39.50
99.40	99.42	99.43	99.45	99.46	99.47	99.47	99.48	99.48	99.49	99.50
999.40	999.42	999.43	999.45	999.46	999.47	999.47	999.48	999.48	999.49	999.50
5.23	5.22	5.20	5.18	5.17	5.17	5.16	5.15	5.15	5.14	5.13
8.79	8.74	8.70	8.66	8.63	8.62	8.59	8.58	8.57	8.55	8.53
14.42	14.34	14.25	14.17	14.12	14.08	14.04	14.01	13.99	13.95	13.91
27.23	27.05	26.87	26.69	26.58	26.50	26.41	26.35	26.32	26.22	26.14
129.25	128.32	127.37	126.42	125.84	125.45	124.96	124.66	124.47	123.97	123.53
3.92	3.90	3.87	3.84	3.83	3.82	3.80	3.80	3.79	3.78	3.76
5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.70	5.69	5.66	5.63
8.84	8.75	8.66	8.56	8.50	8.46	8.41	8.38	8.36	8.31	8.26
14.55	14.37	14.20	14.02	13.91	13.84	13.75	13.69	13.65	13.56	13.47
48.05	47.41	46.76	46.10	45.70	45.43	45.09	44.88	44.75	44.40	44.09
3.30	3.27	3.24	3.21	3.19	3.17	3.16	3.15	3.14	3.12	3.11
4.74	4.68	4.62	4.56	4.52	4.50	4.46	4.44	4.43	4.40	4.37
6.62	6.52	6.43	6.33	6.27	6.23	6.18	6.14	6.12	6.07	6.02
10.05	9.89	9.72	9.55	9.45	9.38	9.29	9.24	9.20	9.11	9.03
26.92	26.42	25.91	25.39	25.08	24.87	24.60	24.44	24.33	24.06	23.82
2.94	2.90	2.87	2.84	2.81	2.80	2.78	2.77	2.76	2.74	2.72
4.06	4.00	3.94	3.87	3.83	3.81	3.77	3.75	3.74	3.70	3.67
5.46	5.37	5.27	5.17	5.11	5.07	5.01	4.98	4.96	4.90	4.86
7.87	7.72	7.56	7.40	7.30	7.23	7.14	7.09	7.06	6.97	6.89
18.41	17.99	17.56	17.12	16.85	16.67	16.44	16.31	16.21	15.98	15.77
2.70	2.67	2.63	2.59	2.57	2.56	2.54	2.52	2.51	2.49	2.47
3.64	3.57	3.51	3.44	3.40	3.38	3.34	3.32	3.30	3.27	3.23
4.76	4.67	4.57	4.47	4.40	4.36	4.31	4.28	4.25	4.20	4.15
6.62	6.47	6.31	6.16	6.06	5.99	5.91	5.86	5.82	5.74	5.66
14.08	13.71	13.32	12.93	12.69	12.53	12.33	12.20	12.12	11.91	11.72

(*Continued*)

TABLE E

F critical values (continued)

Degrees of freedom in the denominator	*p*	1	2	3	4	5	6	7	8	9
		Degrees of freedom in the numerator								
8	.100	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56
	.050	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
	.025	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36
	.010	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91
	.001	25.41	18.49	15.83	14.39	13.48	12.86	12.40	12.05	11.77
9	.100	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44
	.050	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
	.025	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03
	.010	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35
	.001	22.86	16.39	13.90	12.56	11.71	11.13	10.70	10.37	10.11
10	.100	3.29	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35
	.050	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
	.025	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78
	.010	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94
	.001	21.04	14.91	12.55	11.28	10.48	9.93	9.52	9.20	8.96
11	.100	3.23	2.86	2.66	2.54	2.45	2.39	2.34	2.30	2.27
	.050	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
	.025	6.72	5.26	4.63	4.28	4.04	3.88	3.76	3.66	3.59
	.010	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63
	.001	19.69	13.81	11.56	10.35	9.58	9.05	8.66	8.35	8.12
12	.100	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21
	.050	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
	.025	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44
	.010	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39
	.001	18.64	12.97	10.80	9.63	8.89	8.38	8.00	7.71	7.48
13	.100	3.14	2.76	2.56	2.43	2.35	2.28	2.23	2.20	2.16
	.050	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
	.025	6.41	4.97	4.35	4.00	3.77	3.60	3.48	3.39	3.31
	.010	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19
	.001	17.82	12.31	10.21	9.07	8.35	7.86	7.49	7.21	6.98
14	.100	3.10	2.73	2.52	2.39	2.31	2.24	2.19	2.15	2.12
	.050	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
	.025	6.30	4.86	4.24	3.89	3.66	3.50	3.38	3.29	3.21
	.010	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03
	.001	17.14	11.78	9.73	8.62	7.92	7.44	7.08	6.80	6.58
15	.100	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09
	.050	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59
	.025	6.20	4.77	4.15	3.80	3.58	3.41	3.29	3.20	3.12
	.010	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89
	.001	16.59	11.34	9.34	8.25	7.57	7.09	6.74	6.47	6.26
16	.100	3.05	2.67	2.46	2.33	2.24	2.18	2.13	2.09	2.06
	.050	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54
	.025	6.12	4.69	4.08	3.73	3.50	3.34	3.22	3.12	3.05
	.010	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78
	.001	16.12	10.97	9.01	7.94	7.27	6.80	6.46	6.19	5.98
17	.100	3.03	2.64	2.44	2.31	2.22	2.15	2.10	2.06	2.03
	.050	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49
	.025	6.04	4.62	4.01	3.66	3.44	3.28	3.16	3.06	2.98
	.010	8.40	6.11	5.19	4.67	4.34	4.10	3.93	3.79	3.68
	.001	15.72	10.66	8.73	7.68	7.02	6.56	6.22	5.96	5.75

TABLE E

F critical values (continued)

Degrees of freedom in the numerator										
10	12	15	20	25	30	40	50	60	120	1000
2.54	2.50	2.46	2.42	2.40	2.38	2.36	2.35	2.34	2.32	2.30
3.35	3.28	3.22	3.15	3.11	3.08	3.04	3.02	3.01	2.97	2.93
4.30	4.20	4.10	4.00	3.94	3.89	3.84	3.81	3.78	3.73	3.68
5.81	5.67	5.52	5.36	5.26	5.20	5.12	5.07	5.03	4.95	4.87
11.54	11.19	10.84	10.48	10.26	10.11	9.92	9.80	9.73	9.53	9.36
2.42	2.38	2.34	2.30	2.27	2.25	2.23	2.22	2.21	2.18	2.16
3.14	3.07	3.01	2.94	2.89	2.86	2.83	2.80	2.79	2.75	2.71
3.96	3.87	3.77	3.67	3.60	3.56	3.51	3.47	3.45	3.39	3.34
5.26	5.11	4.96	4.81	4.71	4.65	4.57	4.52	4.48	4.40	4.32
9.89	9.57	9.24	8.90	8.69	8.55	8.37	8.26	8.19	8.00	7.84
2.32	2.28	2.24	2.20	2.17	2.16	2.13	2.12	2.11	2.08	2.06
2.98	2.91	2.85	2.77	2.73	2.70	2.66	2.64	2.62	2.58	2.54
3.72	3.62	3.52	3.42	3.35	3.31	3.26	3.22	3.20	3.14	3.09
4.85	4.71	4.56	4.41	4.31	4.25	4.17	4.12	4.08	4.00	3.92
8.75	8.45	8.13	7.80	7.60	7.47	7.30	7.19	7.12	6.94	6.78
2.25	2.21	2.17	2.12	2.10	2.08	2.05	2.04	2.03	2.00	1.98
2.85	2.79	2.72	2.65	2.60	2.57	2.53	2.51	2.49	2.45	2.41
3.53	3.43	3.33	3.23	3.16	3.12	3.06	3.03	3.00	2.94	2.89
4.54	4.40	4.25	4.10	4.01	3.94	3.86	3.81	3.78	3.69	3.61
7.92	7.63	7.32	7.01	6.81	6.68	6.52	6.42	6.35	6.18	6.02
2.19	2.15	2.10	2.06	2.03	2.01	1.99	1.97	1.96	1.93	1.91
2.75	2.69	2.62	2.54	2.50	2.47	2.43	2.40	2.38	2.34	2.30
3.37	3.28	3.18	3.07	3.01	2.96	2.91	2.87	2.85	2.79	2.73
4.30	4.16	4.01	3.86	3.76	3.70	3.62	3.57	3.54	3.45	3.37
7.29	7.00	6.71	6.40	6.22	6.09	5.93	5.83	5.76	5.59	5.44
2.14	2.10	2.05	2.01	1.98	1.96	1.93	1.92	1.90	1.88	1.85
2.67	2.60	2.53	2.46	2.41	2.38	2.34	2.31	2.30	2.25	2.21
3.25	3.15	3.05	2.95	2.88	2.84	2.78	2.74	2.72	2.66	2.60
4.10	3.96	3.82	3.66	3.57	3.51	3.43	3.38	3.34	3.25	3.18
6.80	6.52	6.23	5.93	5.75	5.63	5.47	5.37	5.30	5.14	4.99
2.10	2.05	2.01	1.96	1.93	1.91	1.89	1.87	1.86	1.83	1.80
2.60	2.53	2.46	2.39	2.34	2.31	2.27	2.24	2.22	2.18	2.14
3.15	3.05	2.95	2.84	2.78	2.73	2.67	2.64	2.61	2.55	2.50
3.94	3.80	3.66	3.51	3.41	3.35	3.27	3.22	3.18	3.09	3.02
6.40	6.13	5.85	5.56	5.38	5.25	5.10	5.00	4.94	4.77	4.62
2.06	2.02	1.97	1.92	1.89	1.87	1.85	1.83	1.82	1.79	1.76
2.54	2.48	2.40	2.33	2.28	2.25	2.20	2.18	2.16	2.11	2.07
3.06	2.96	2.86	2.76	2.69	2.64	2.59	2.55	2.52	2.46	2.40
3.80	3.67	3.52	3.37	3.28	3.21	3.13	3.08	3.05	2.96	2.88
6.08	5.81	5.54	5.25	5.07	4.95	4.80	4.70	4.64	4.47	4.33
2.03	1.99	1.94	1.89	1.86	1.84	1.81	1.79	1.78	1.75	1.72
2.49	2.42	2.35	2.28	2.23	2.19	2.15	2.12	2.11	2.06	2.02
2.99	2.89	2.79	2.68	2.61	2.57	2.51	2.47	2.45	2.38	2.32
3.69	3.55	3.41	3.26	3.16	3.10	3.02	2.97	2.93	2.84	2.76
5.81	5.55	5.27	4.99	4.82	4.70	4.54	4.45	4.39	4.23	4.08
2.00	1.96	1.91	1.86	1.83	1.81	1.78	1.76	1.75	1.72	1.69
2.45	2.38	2.31	2.23	2.18	2.15	2.10	2.08	2.06	2.01	1.97
2.92	2.82	2.72	2.62	2.55	2.50	2.44	2.41	2.38	2.32	2.26
3.59	3.46	3.31	3.16	3.07	3.00	2.92	2.87	2.83	2.75	2.66
5.58	5.32	5.05	4.78	4.60	4.48	4.33	4.24	4.18	4.02	3.87

(Continued)

TABLE E

F critical values (continued)

Degrees of freedom in the denominator	*p*	1	2	3	4	5	6	7	8	9
		Degrees of freedom in the numerator								
18	.100	3.01	2.62	2.42	2.29	2.20	2.13	2.08	2.04	2.00
	.050	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46
	.025	5.98	4.56	3.95	3.61	3.38	3.22	3.10	3.01	2.93
	.010	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60
	.001	15.38	10.39	8.49	7.46	6.81	6.35	6.02	5.76	5.56
19	.100	2.99	2.61	2.40	2.27	2.18	2.11	2.06	2.02	1.98
	.050	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42
	.025	5.92	4.51	3.90	3.56	3.33	3.17	3.05	2.96	2.88
	.010	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52
	.001	15.08	10.16	8.28	7.27	6.62	6.18	5.85	5.59	5.39
20	.100	2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96
	.050	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39
	.025	5.87	4.46	3.86	3.51	3.29	3.13	3.01	2.91	2.84
	.010	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46
	.001	14.82	9.95	8.10	7.10	6.46	6.02	5.69	5.44	5.24
21	.100	2.96	2.57	2.36	2.23	2.14	2.08	2.02	1.98	1.95
	.050	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37
	.025	5.83	4.42	3.82	3.48	3.25	3.09	2.97	2.87	2.80
	.010	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40
	.001	14.59	9.77	7.94	6.95	6.32	5.88	5.56	5.31	5.11
22	.100	2.95	2.56	2.35	2.22	2.13	2.06	2.01	1.97	1.93
	.050	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34
	.025	5.79	4.38	3.78	3.44	3.22	3.05	2.93	2.84	2.76
	.010	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35
	.001	14.38	9.61	7.80	6.81	6.19	5.76	5.44	5.19	4.99
23	.100	2.94	2.55	2.34	2.21	2.11	2.05	1.99	1.95	1.92
	.050	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32
	.025	5.75	4.35	3.75	3.41	3.18	3.02	2.90	2.81	2.73
	.010	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30
	.001	14.20	9.47	7.67	6.70	6.08	5.65	5.33	5.09	4.89
24	.100	2.93	2.54	2.33	2.19	2.10	2.04	1.98	1.94	1.91
	.050	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30
	.025	5.72	4.32	3.72	3.38	3.15	2.99	2.87	2.78	2.70
	.010	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26
	.001	14.03	9.34	7.55	6.59	5.98	5.55	5.23	4.99	4.80
25	.100	2.92	2.53	2.32	2.18	2.09	2.02	1.97	1.93	1.89
	.050	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28
	.025	5.69	4.29	3.69	3.35	3.13	2.97	2.85	2.75	2.68
	.010	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22
	.001	13.88	9.22	7.45	6.49	5.89	5.46	5.15	4.91	4.71
26	.100	2.91	2.52	2.31	2.17	2.08	2.01	1.96	1.92	1.88
	.050	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27
	.025	5.66	4.27	3.67	3.33	3.10	2.94	2.82	2.73	2.65
	.010	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18
	.001	13.74	9.12	7.36	6.41	5.80	5.38	5.07	4.83	4.64
27	.100	2.90	2.51	2.30	2.17	2.07	2.00	1.95	1.91	1.87
	.050	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25
	.025	5.63	4.24	3.65	3.31	3.08	2.92	2.80	2.71	2.63
	.010	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15
	.001	13.61	9.02	7.27	6.33	5.73	5.31	5.00	4.76	4.57

TABLE E

F critical values (continued)

Degrees of freedom in the numerator										
10	12	15	20	25	30	40	50	60	120	1000
1.98	1.93	1.89	1.84	1.80	1.78	1.75	1.74	1.72	1.69	1.66
2.41	2.34	2.27	2.19	2.14	2.11	2.06	2.04	2.02	1.97	1.92
2.87	2.77	2.67	2.56	2.49	2.44	2.38	2.35	2.32	2.26	2.20
3.51	3.37	3.23	3.08	2.98	2.92	2.84	2.78	2.75	2.66	2.58
5.39	5.13	4.87	4.59	4.42	4.30	4.15	4.06	4.00	3.84	3.69
1.96	1.91	1.86	1.81	1.78	1.76	1.73	1.71	1.70	1.67	1.64
2.38	2.31	2.23	2.16	2.11	2.07	2.03	2.00	1.98	1.93	1.88
2.82	2.72	2.62	2.51	2.44	2.39	2.33	2.30	2.27	2.20	2.14
3.43	3.30	3.15	3.00	2.91	2.84	2.76	2.71	2.67	2.58	2.50
5.22	4.97	4.70	4.43	4.26	4.14	3.99	3.90	3.84	3.68	3.53
1.94	1.89	1.84	1.79	1.76	1.74	1.71	1.69	1.68	1.64	1.61
2.35	2.28	2.20	2.12	2.07	2.04	1.99	1.97	1.95	1.90	1.85
2.77	2.68	2.57	2.46	2.40	2.35	2.29	2.25	2.22	2.16	2.09
3.37	3.23	3.09	2.94	2.84	2.78	2.69	2.64	2.61	2.52	2.43
5.08	4.82	4.56	4.29	4.12	4.00	3.86	3.77	3.70	3.54	3.40
1.92	1.87	1.83	1.78	1.74	1.72	1.69	1.67	1.66	1.62	1.59
2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.94	1.92	1.87	1.82
2.73	2.64	2.53	2.42	2.36	2.31	2.25	2.21	2.18	2.11	2.05
3.31	3.17	3.03	2.88	2.79	2.72	2.64	2.58	2.55	2.46	2.37
4.95	4.70	4.44	4.17	4.00	3.88	3.74	3.64	3.58	3.42	3.28
1.90	1.86	1.81	1.76	1.73	1.70	1.67	1.65	1.64	1.60	1.57
2.30	2.23	2.15	2.07	2.02	1.98	1.94	1.91	1.89	1.84	1.79
2.70	2.60	2.50	2.39	2.32	2.27	2.21	2.17	2.14	2.08	2.01
3.26	3.12	2.98	2.83	2.73	2.67	2.58	2.53	2.50	2.40	2.32
4.83	4.58	4.33	4.06	3.89	3.78	3.63	3.54	3.48	3.32	3.17
1.89	1.84	1.80	1.74	1.71	1.69	1.66	1.64	1.62	1.59	1.55
2.27	2.20	2.13	2.05	2.00	1.96	1.91	1.88	1.86	1.81	1.76
2.67	2.57	2.47	2.36	2.29	2.24	2.18	2.14	2.11	2.04	1.98
3.21	3.07	2.93	2.78	2.69	2.62	2.54	2.48	2.45	2.35	2.27
4.73	4.48	4.23	3.96	3.79	3.68	3.53	3.44	3.38	3.22	3.08
1.88	1.83	1.78	1.73	1.70	1.67	1.64	1.62	1.61	1.57	1.54
2.25	2.18	2.11	2.03	1.97	1.94	1.89	1.86	1.84	1.79	1.74
2.64	2.54	2.44	2.33	2.26	2.21	2.15	2.11	2.08	2.01	1.94
3.17	3.03	2.89	2.74	2.64	2.58	2.49	2.44	2.40	2.31	2.22
4.64	4.39	4.14	3.87	3.71	3.59	3.45	3.36	3.29	3.14	2.99
1.87	1.82	1.77	1.72	1.68	1.66	1.63	1.61	1.59	1.56	1.52
2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.84	1.82	1.77	1.72
2.61	2.51	2.41	2.30	2.23	2.18	2.12	2.08	2.05	1.98	1.91
3.13	2.99	2.85	2.70	2.60	2.54	2.45	2.40	2.36	2.27	2.18
4.56	4.31	4.06	3.79	3.63	3.52	3.37	3.28	3.22	3.06	2.91
1.86	1.81	1.76	1.71	1.67	1.65	1.61	1.59	1.58	1.54	1.51
2.22	2.15	2.07	1.99	1.94	1.90	1.85	1.82	1.80	1.75	1.70
2.59	2.49	2.39	2.28	2.21	2.16	2.09	2.05	2.03	1.95	1.89
3.09	2.96	2.81	2.66	2.57	2.50	2.42	2.36	2.33	2.23	2.14
4.48	4.24	3.99	3.72	3.56	3.44	3.30	3.21	3.15	2.99	2.84
1.85	1.80	1.75	1.70	1.66	1.64	1.60	1.58	1.57	1.53	1.50
2.20	2.13	2.06	1.97	1.92	1.88	1.84	1.81	1.79	1.73	1.68
2.57	2.47	2.36	2.25	2.18	2.13	2.07	2.03	2.00	1.93	1.86
3.06	2.93	2.78	2.63	2.54	2.47	2.38	2.33	2.29	2.20	2.11
4.41	4.17	3.92	3.66	3.49	3.38	3.23	3.14	3.08	2.92	2.78

(Continued)

TABLE E

F critical values (continued)

Degrees of freedom in the denominator	*p*	1	2	3	4	5	6	7	8	9
		Degrees of freedom in the numerator								
28	.100	2.89	2.50	2.29	2.16	2.06	2.00	1.94	1.90	1.87
	.050	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24
	.025	5.61	4.22	3.63	3.29	3.06	2.90	2.78	2.69	2.61
	.010	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12
	.001	13.50	8.93	7.19	6.25	5.66	5.24	4.93	4.69	4.50
29	.100	2.89	2.50	2.28	2.15	2.06	1.99	1.93	1.89	1.86
	.050	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22
	.025	5.59	4.20	3.61	3.27	3.04	2.88	2.76	2.67	2.59
	.010	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09
	.001	13.39	8.85	7.12	6.19	5.59	5.18	4.87	4.64	4.45
30	.100	2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.88	1.85
	.050	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21
	.025	5.57	4.18	3.59	3.25	3.03	2.87	2.75	2.65	2.57
	.010	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07
	.001	13.29	8.77	7.05	6.12	5.53	5.12	4.82	4.58	4.39
40	.100	2.84	2.44	2.23	2.09	2.00	1.93	1.87	1.83	1.79
	.050	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12
	.025	5.42	4.05	3.46	3.13	2.90	2.74	2.62	2.53	2.45
	.010	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89
	.001	12.61	8.25	6.59	5.70	5.13	4.73	4.44	4.21	4.02
50	.100	2.81	2.41	2.20	2.06	1.97	1.90	1.84	1.80	1.76
	.050	4.03	3.18	2.79	2.56	2.40	2.29	2.20	2.13	2.07
	.025	5.34	3.97	3.39	3.05	2.83	2.67	2.55	2.46	2.38
	.010	7.17	5.06	4.20	3.72	3.41	3.19	3.02	2.89	2.78
	.001	12.22	7.96	6.34	5.46	4.90	4.51	4.22	4.00	3.82
60	.100	2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74
	.050	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04
	.025	5.29	3.93	3.34	3.01	2.79	2.63	2.51	2.41	2.33
	.010	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72
	.001	11.97	7.77	6.17	5.31	4.76	4.37	4.09	3.86	3.69
100	.100	2.76	2.36	2.14	2.00	1.91	1.83	1.78	1.73	1.69
	.050	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.97
	.025	5.18	3.83	3.25	2.92	2.70	2.54	2.42	2.32	2.24
	.010	6.90	4.82	3.98	3.51	3.21	2.99	2.82	2.69	2.59
	.001	11.50	7.41	5.86	5.02	4.48	4.11	3.83	3.61	3.44
200	.100	2.73	2.33	2.11	1.97	1.88	1.80	1.75	1.70	1.66
	.050	3.89	3.04	2.65	2.42	2.26	2.14	2.06	1.98	1.93
	.025	5.10	3.76	3.18	2.85	2.63	2.47	2.35	2.26	2.18
	.010	6.76	4.71	3.88	3.41	3.11	2.89	2.73	2.60	2.50
	.001	11.15	7.15	5.63	4.81	4.29	3.92	3.65	3.43	3.26
1000	.100	2.71	2.31	2.09	1.95	1.85	1.78	1.72	1.68	1.64
	.050	3.85	3.00	2.61	2.38	2.22	2.11	2.02	1.95	1.89
	.025	5.04	3.70	3.13	2.80	2.58	2.42	2.30	2.20	2.13
	.010	6.66	4.63	3.80	3.34	3.04	2.82	2.66	2.53	2.43
	.001	10.89	6.96	5.46	4.65	4.14	3.78	3.51	3.30	3.13

TABLE E

F critical values (continued)

Degrees of freedom in the numerator										
10	12	15	20	25	30	40	50	60	120	1000
1.84	1.79	1.74	1.69	1.65	1.63	1.59	1.57	1.56	1.52	1.48
2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.79	1.77	1.71	1.66
2.55	2.45	2.34	2.23	2.16	2.11	2.05	2.01	1.98	1.91	1.84
3.03	2.90	2.75	2.60	2.51	2.44	2.35	2.30	2.26	2.17	2.08
4.35	4.11	3.86	3.60	3.43	3.32	3.18	3.09	3.02	2.86	2.72
1.83	1.78	1.73	1.68	1.64	1.62	1.58	1.56	1.55	1.51	1.47
2.18	2.10	2.03	1.94	1.89	1.85	1.81	1.77	1.75	1.70	1.65
2.53	2.43	2.32	2.21	2.14	2.09	2.03	1.99	1.96	1.89	1.82
3.00	2.87	2.73	2.57	2.48	2.41	2.33	2.27	2.23	2.14	2.05
4.29	4.05	3.80	3.54	3.38	3.27	3.12	3.03	2.97	2.81	2.66
1.82	1.77	1.72	1.67	1.63	1.61	1.57	1.55	1.54	1.50	1.46
2.16	2.09	2.01	1.93	1.88	1.84	1.79	1.76	1.74	1.68	1.63
2.51	2.41	2.31	2.20	2.12	2.07	2.01	1.97	1.94	1.87	1.80
2.98	2.84	2.70	2.55	2.45	2.39	2.30	2.25	2.21	2.11	2.02
4.24	4.00	3.75	3.49	3.33	3.22	3.07	2.98	2.92	2.76	2.61
1.76	1.71	1.66	1.61	1.57	1.54	1.51	1.48	1.47	1.42	1.38
2.08	2.00	1.92	1.84	1.78	1.74	1.69	1.66	1.64	1.58	1.52
2.39	2.29	2.18	2.07	1.99	1.94	1.88	1.83	1.80	1.72	1.65
2.80	2.66	2.52	2.37	2.27	2.20	2.11	2.06	2.02	1.92	1.82
3.87	3.64	3.40	3.14	2.98	2.87	2.73	2.64	2.57	2.41	2.25
1.73	1.68	1.63	1.57	1.53	1.50	1.46	1.44	1.42	1.38	1.33
2.03	1.95	1.87	1.78	1.73	1.69	1.63	1.60	1.58	1.51	1.45
2.32	2.22	2.11	1.99	1.92	1.87	1.80	1.75	1.72	1.64	1.56
2.70	2.56	2.42	2.27	2.17	2.10	2.01	1.95	1.91	1.80	1.70
3.67	3.44	3.20	2.95	2.79	2.68	2.53	2.44	2.38	2.21	2.05
1.71	1.66	1.60	1.54	1.50	1.48	1.44	1.41	1.40	1.35	1.30
1.99	1.92	1.84	1.75	1.69	1.65	1.59	1.56	1.53	1.47	1.40
2.27	2.17	2.06	1.94	1.87	1.82	1.74	1.70	1.67	1.58	1.49
2.63	2.50	2.35	2.20	2.10	2.03	1.94	1.88	1.84	1.73	1.62
3.54	3.32	3.08	2.83	2.67	2.55	2.41	2.32	2.25	2.08	1.92
1.66	1.61	1.56	1.49	1.45	1.42	1.38	1.35	1.34	1.28	1.22
1.93	1.85	1.77	1.68	1.62	1.57	1.52	1.48	1.45	1.38	1.30
2.18	2.08	1.97	1.85	1.77	1.71	1.64	1.59	1.56	1.46	1.36
2.50	2.37	2.22	2.07	1.97	1.89	1.80	1.74	1.69	1.57	1.45
3.30	3.07	2.84	2.59	2.43	2.32	2.17	2.08	2.01	1.83	1.64
1.63	1.58	1.52	1.46	1.41	1.38	1.34	1.31	1.29	1.23	1.16
1.88	1.80	1.72	1.62	1.56	1.52	1.46	1.41	1.39	1.30	1.21
2.11	2.01	1.90	1.78	1.70	1.64	1.56	1.51	1.47	1.37	1.25
2.41	2.27	2.13	1.97	1.87	1.79	1.69	1.63	1.58	1.45	1.30
3.12	2.90	2.67	2.42	2.26	2.15	2.00	1.90	1.83	1.64	1.43
1.61	1.55	1.49	1.43	1.38	1.35	1.30	1.27	1.25	1.18	1.08
1.84	1.76	1.68	1.58	1.52	1.47	1.41	1.36	1.33	1.24	1.11
2.06	1.96	1.85	1.72	1.64	1.58	1.50	1.45	1.41	1.29	1.13
2.34	2.20	2.06	1.90	1.79	1.72	1.61	1.54	1.50	1.35	1.16
2.99	2.77	2.54	2.30	2.14	2.02	1.87	1.77	1.69	1.49	1.22