Australian School of Business

Working Paper

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Australian School of Business

Australian School of Business Research Paper No. 2014 ECON 13

Housing Supply Elasticity in Sydney Local Government Areas

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March 2014

Abstract
We report supply elasticity estimates of residential property (houses and apartments) for Local Government Areas (LGAs) in metropolitan Sydney. Using annual data for 1991-2012, the average supply elasticity estimate across all LGAs is 0.2 for houses and 0.8 for apartments. The supply of houses is inelastic in all 43 LGAs; in contrast apartment supply is elastic – greater than unity – in about one-third of LGAs. We develop a model to explain the cross-section variation in supply elasticity across LGAs. For houses, supply elasticity is negatively related to an LGA's population density, the time taken by a Local Council to process a development application and to various measures of the amount of land in an LGA that is unavailable for new housing development. Variation in supply elasticity for apartments across LGAs is unrelated to any of the available regressors.

JEL Classification: R31, R52

Keywords: housing supply, supply elasticity, development application, undevelopable land

1. Introduction

Existing empirical studies indicate the supply elasticity of new housing in Australia is relatively inelastic (Ball, Meen and Nygaard, 2010; Sánchez and Johansson, 2011; Gitelman and Otto, 2012). Ball et. al. and Sánchez and Johansson both report economy-wide estimates of about 0.5. Gitelman and Otto (2012) estimate housing supply elasticities for Sydney – and at the aggregate level – find inelastic supply curves for both houses and apartments. These authors also present some evidence suggesting that supply elasticity varies across geographic regions of Sydney, although they do not – due to data limitations – examine the possible causes of such variation.

In this paper we extend the analysis of Gitelman and Otto by constructing an annual series for the stock of houses and apartments at the LGA-level for Sydney from 1991-2012. This allows us to obtain estimates of supply elasticities for houses and apartments in each of the 43 LGAs in metropolitan Sydney. We then look for factors that might explain the variation in housing supply elasticity across LGAs. Similar research on housing markets in the United States points to the importance of natural geography and government regulation as being key influences on variation in supply elasticity across different locations (Green, Malpezzi, and Mayo, 2005; Saiz, 2010).

There are two components to the econometric analysis in this paper. The initial part of the analysis is to obtain estimates of the supply elasticity for houses and apartments in each LGA. The methodology and results are reported in Section 2. In the second stage of the paper we seek to develop a model that can explain the cross-section distribution of the estimated supply elasticities. The model and its estimates are reported in Section 3. Section 4 concludes.

2. Estimating Supply Elasticity

2.1 Modeling Framework

For each LGA, we have 22 annual observations for the period 1991 to 2012 to estimate supply elasticity. The model of the supply curve in a particular LGA takes the following form:

$$lnQ_t^i = \alpha_i + \beta_i lnP_t^i + u_t^i \qquad (1)$$

where the housing stock is a log-linear function of the real (or relative) price of housing, and β_i is the supply elasticity in the *i*'th LGA. While this is a very restricted model, its use is necessitated by a lack of data on other variables that might affect the supply curve. Omitted variables that could affect the supply of housing include: the level of productivity in housing construction; factor prices; expectations of future prices; property taxes and government regulations. Currently time series measures of such variables are not available at the LGA (or even the city) level.

For identification of the housing supply curve, it is necessary that the corresponding demand curve for housing, in an LGA, contains exogenous variables that can be excluded (*a priori*) from the supply curve. We assume the (inverse) demand curve for housing has the following form:

$$lnP_t^i = \delta_i + \theta_i lnQ_t^i + \boldsymbol{Z_t^{i}}'\boldsymbol{\gamma_i} + v_t^i \qquad (2)$$

where $\boldsymbol{Z_t^i}$ is a vector of exogenous demand-shifters that can be excluded from the housing supply curve. In this study the three variables that we include in $\boldsymbol{Z_t^i}$ are real per-capita income, population and a real interest rate, where the latter variable does not vary across LGAs.

The supply and demand model for housing represented by equations (1) and (2) implies that price and quantity are simultaneously determined and simple algebra leads to a basic recognition that $E(lnP_t^i u_t^i) \neq 0$ in (1). Consequently use of ordinary least squares to estimate the supply elasticity will generally produce biased and inconsistent estimates. One way to address this problem is by estimating (1) using instrumental variables (IV), with the vector of exogenous demand shifters $\boldsymbol{Z_t^i}$ as instruments. Potential issues of serial correlation and heteroskedasticity in the error term u_t^i can be accounted for in the IV regression using robust standard errors (Newey and West, 1987).

A feature of the supply curve for housing – given by (1) – is that both the quantity and price variables enter in (log) levels[1]. This raises the possibility that the variables under consideration may be non-stationary due to the presence of stochastic (rather than deterministic) trends. If the data on housing prices and quantities do exhibit stochastic trends, then for equation (1) to represent a valid long-run supply curve u_t^i must be stationary and lnQ_t^i and lnP_t^i co-integrated. If this is not the case – and equation (1) is a spurious regression – then the IV estimator will not be consistent. As a check on the reliability and robustness of the IV estimates, we also estimate equation (1) using the ARDL bounds procedure developed by Pesaran, Shin and Smith (2001). A useful feature of the ARDL methodology is that it allows for a formal test of whether a relationship – in levels – exists between lnQ_t^i and lnP_t^i.

2.2 Data

Data are collected for the 43 LGAs that comprise the Sydney metropolitan area. Residential property prices for each LGA are measured using median prices obtained from the NSW Department of Housing's *Sales Reports*. Quarterly observations are available – for most LGAs – from March 1991 to

[1] In their study for the United States, Green, Malpezzi and Mayo (2005), with 18 annual observations for each metropolitan statistical area (MSA), regressed the percentage change in the housing stock on the (lagged) first-difference of the log of the house price index. Such a specification – in first-differences – does not yield sensible estimates for our data set.

June 2012[2]. The price data are classified by strata and non-strata property types. In this paper we refer to non-strata properties as houses and strata properties as apartments. To obtain an annual frequency for prices we compute the average of the quarterly observations for each financial year; yielding 22 observations for house and apartment prices in each LGA.

The quantity of housing is measured by the annual number of private residential properties in each LGA. The data is constructed by combining Australian Bureau of Statistics (ABS) Census housing stock figures for the years 1991, 1996, 2001, 2006 and 2012, with figures on housing approvals for the financial years 1992 to 2012 (sourced from *Regional Statistics Profiles* for New South Wales, 1992-2003, and the Australian *National Regional Profile* for the remaining years, 2004-2012). In effect the housing approval numbers are used to interpolate housing stocks for the inter-censual years[3].

Estimates of income for LGAs are based on data from the Australian Taxation Office's *Taxation Statistics.* For the period 1990-91 to 2005-06 the Bureau of Infrastructure, Transport and Regional Economics (BITRE) reports real income per taxpayer in 2007-08 prices by LGA (using figures derived from Australian Taxation Office data and the consumer price index (CPI) for Australia). For the period 2006-07 to 2009-10, the ABS reports data by LGA for nominal income per taxpayer in their *National Regional Profile 2007-2011.* We convert the latter figures to constant 2007-08 prices using the CPI for Australia. Finally, since there is no comparable income data by LGA for the financial years 2010-11 and 2011-12, we simply assume that the growth rate of real income per taxpayer in these two years is equal to the growth rate for 2009-10.

Data for population are obtained from a number of sources. Population estimates (preliminary) for LGAs for the period of 1990-1991 to 1994-1995 are produced by the NSW Local Grants Commission. For the remaining financial years (1995-1996 to 2011-2012), estimated population by LGA are obtained from the ABS.

Additional variables used in estimating the supply elasticity are the CPI for Sydney and the real interest rate. The financial year CPI is found by averaging across relevant quarterly data. To transform the house price series to real terms, each series is divided by the CPI for Sydney. The real interest rate is the financial year average yield on the Australian Government indexed bond with the longest maturity.

3.3 Supply Elasticity Estimates

[2] For some LGAs observations at the beginning of the sample period are missing and need to be interpolated from price data for other LGAs.
[3] Precise details of this procedure and other data sources are provided in the Data Appendix.

In this section, we report and analyze the estimates of supply elasticity in each LGA obtained from the IV and the ARDL estimators. Table 1 contains a numbered list of the LGAs which can be used in interpreting the various figures in this section.

3.3.1 Instrumental Variables

Given the potential endogeneity of housing prices in equation (1) we estimate the model by instrumental variables. The instruments used are real income per taxpayer, population and the real bond rate. The data for the first two variables vary by LGA, but the real interest rate does not. Equations (1) and (2) and our choice of instruments imply a reduced-form model for house prices of the following form:

$$lnP_t^i = \pi_{i0} + \pi_{i1} lny_t^i + \pi_{i2} lnpop_t^i + \pi_{i3} r10_t + e_t^i \qquad (4)$$

To test for instrument quality/relevance we compute the F-statistic for $\pi_{i1} = \pi_{i2} = \pi_{i3} = 0$ and compare it to the appropriate critical values computed by Stock and Yogo (2002). Figure 1 reports the F-statistics associated with the regressions of house prices and apartment prices on the three instruments for each LGA. From Stock and Yogo the critical value for a test (at the 5% level of significance) that the IV relative bias (i.e. relative to OLS) exceeds 10% is 9.08; so it is evident from Figure 1 that this hypothesis is always rejected. Weak instruments are unlikely to be a serious problem with the IV estimation of the supply elasticity.

Figures 2 and 3 report the supply elasticity estimates for houses and apartments respectively[4]. It is clear from Figure 2 the supply curve for houses is inelastic in all LGAs. The average elasticity across the 43 LGAs is only 0.22 (while the median elasticity is lower at 0.15). In only five LGAs is the estimated supply elasticity for houses greater than one-half (Camden, 0.96; Baulkham Hills, 0.71; Liverpool, 0.66; Wyong, 0.55; and Wollondilly, 0.50). The LGAs in Sydney with the lowest estimated supply elasticity for houses are Lane Cove (0.05), Mosman (0.05), Wollahra (0.05) and Kogarah (0.06).

Figure 3 reports the estimated supply elasticity for apartments in each LGA. In all but three LGAs (Blue Mountains, Camden and Liverpool) the estimated supply elasticity for apartments is larger than for houses. Just under one-third of LGAs are found to have supply elasticities for apartments greater than unity. The largest estimates in Figure 3 correspond to Baulkham Hills (4.3) and Bankstown (2.3). The average supply elasticity across all LGAs is 0.80 (with the median being 0.56). On average the supply elasticity for apartments is about 3.5 times that for houses[5].

[4] The estimates – along with the Newey-West standard errors – are reported in Table A1 in the Appendix.
[5] This ratio is of similar magnitude to Gitelman and Otto's (2011) finding using panel data for Sydney.

One anomalous result in the supply elasticity estimates for apartments is the negative figure for the Blue Mountains. To understand this result we can see from Figure 4 – which shows a scatter-plot of prices and quantities – that there appears to be evidence of a structural break in the supply relationship for apartments over the period 1991-2012. During the period 2003-2012 both the number and price of apartments in the Blue Mountains declined.

3.3.2 ARDL Bounds Procedure

As a check on the reliability and robustness of the IV estimates for supply elasticity we also employ the ARDL bounds procedure due to Pesaran, Shin and Smith (2001). The ARDL approach can be used to test for the presence of a relationship in levels regardless of whether the variables in (1) are trend or first-difference stationary. Provided the null hypothesis of no-levels relationship is rejected, we can also use the estimates from the ARDL model to estimate β_i.

One issue that does arise with using the ARDL procedure is the need to assume that one of the variables in the supply curve can be treated as being weakly exogenous. In using IV to estimate (1) we have treated lnQ_t^i and lnP_t^i as being simultaneously determined. However for the ARDL analysis we assume it is valid to condition on either lnQ_t^i or lnP_t^i, and since it is not evident which is the more reasonable assumption, we estimate both possible conditional error correction models. Since there is only a relatively small sample of observations for each LGA, we use the following parsimonious specifications for the ARDL models:

$$\Delta lnQ_t = \delta_{Q0} + \delta_{QD}D_{0204} + \delta_{QP}lnP_{t-1} + \delta_{QQ}lnQ_{t-1} + \theta_{QP0}\Delta lnP_t + \varepsilon_{Qt} \qquad (5a)$$

$$\Delta lnP_t = \delta_{P0} + \delta_{PD}D_{0204} + \delta_{PP}lnP_{t-1} + \delta_{PQ}lnQ_{t-1} + \theta_{PQ0}\Delta lnQ_t + \varepsilon_{Pt} \qquad (5b)$$

Finally given the sharp increase in residential property prices around 2002 – which is not well explained by the standard ARDL regressors – we augment these specifications with a dummy variable D_{0204}, that takes the value 1 for the years 2002, 2003 and 2004 and zero elsewhere.

We can test for the presence of a relationship in (log) levels by testing the null hypothesis $H_o\colon \delta_{QP} = \delta_{QQ} = 0$ in equation (5a), or $H_o\colon \delta_{PP} = \delta_{PQ} = 0$ in (5b), using an F-statistic. Since we do not know the order of integration of the two variables, this hypothesis test takes the form of a bounds test. The asymptotic critical values for the ADRL bounds F-test are [4.94, 5.73] at the 5% level of significance, see Pesaran, Shin and Smith, (2001, Table CI(iii)). If the F-statistic is less than 4.94 or greater than 5.73 we can make a decision about the null hypothesis, without knowing if the series are I(1) or I(0). Provided we can reject the null hypothesis of no-levels relationship using either (5a) or (5b), an estimate of the long-run supply elasticity β_i in (1) can be computed using the relevant ratio $\frac{\delta_{QP}}{\delta_{QQ}}$ or $\frac{\delta_{PP}}{\delta_{PQ}}$. These ratios provide an alternative set of estimates of the supply elasticity to the IV estimator.

Figure 5 reports the F-statistic for houses for the two specifications (5a) and 5(b), while Figure 6 reports the same test statistic for apartments.[6] In the case of houses there are only ten LGAs where the hypothesis of no-levels relationship cannot be rejected using *both* (5a) and (5b). For the majority of LGAs at least one of the ARDL models allows for rejection of the null hypothesis of no relationship in levels between lnQ_t^i and lnP_t^i. However in the case of apartments (Figure 6) the evidence against the null of no levels relationship is considerably weaker than for houses. There are twenty-four LGAs in which the hypothesis of no-levels relationship is not rejected by both the ARDL models.

For our analysis the primary question is whether – when the bounds test points to evidence of a levels relationship – the ARDL model yields an estimated elasticity that is similar in magnitude to the IV estimate. Figures 7 and 8 present a scatter-plot of the IV estimate and an ARDL estimate for those LGAs where the hypothesis of no-levels relationship is rejected or where the bounds test is inconclusive. It is apparent that there is a reasonably strong positive correlation between the supply elasticity estimates obtained from the two estimators. On balance the ARDL estimates – particularly for houses – are broadly consistent with those obtained from the IV estimator; and this suggests the IV estimates are robust to possible stochastic non-stationarity in the data.

4. A Cross-Section Model of Supply Elasticity

In this section of the analysis we develop a model to explain the cross-section distribution of the supply elasticity estimates across LGAs. Figure 9 shows estimated density functions (using a Epanechnikov kernel) for the IV estimates of the supply elasticities for houses and apartments.

4.1 Modeling Framework

The cross-section model has the following general form:

$$\hat{\beta}_i = c_0 + \boldsymbol{X}_i'\boldsymbol{\theta}_i + \epsilon_i \tag{7}$$

where $\hat{\beta}_i$ is an estimate of supply elasticity in the i'th LGA and $\boldsymbol{X}_i$ is a vector of cross-section explanatory variables. Similar models are estimated by Green, Malpezzi, and Mayo (2005) and Saiz (2010) for major US cities. These studies point to cross-city differences in regulatory constraints and in natural geography as being the major sources of regional variation in housing supply elasticity.
In our analysis we require explanatory variables that vary across LGAs. While the availability of such variables is limited, we are able to obtain the following explanatory variables: the distance of an LGA

[6] A full set of estimates are reported in Tables A2 and A3 in the Appendix.

from the central business district (CBD) of Sydney[7]; the population density of an LGA; a measure of the average time taken by a Local Council to decide on a development application (DA) and four geographic variables that measure the proportion of land in an LGA that is unavailable for residential development. The cross-section regressions use the supply elasticity estimates obtained by instrumental variables as the dependent variable and separate models are estimated for houses and for apartments.

4.2 Data

The distance of an LGA from the Sydney CBD is measured as the average of the distances to the CBD of the suburbs that make-up the LGA.[8] The population density of an LGA equals the ratio of its resident population to its area and is measured as the number of people per square kilometer. Median and mean times required by Local Councils to decide on a DA are reported in *Comparative Information on NSW Local Government,* and are available from 1994-95 to 2011-12.

We construct four geographic variables (called *Geo1, Geo2, Geo3 and Geo4*) that are designed to measure proportion of land in an LGA that is potentially unavailable for residential development. This is done by seeking to identify those areas of land within the total area of an LGA that are likely to be unavailable (or relatively costly) to use for new housing.[9]

The initial indicator of unavailable land (*Geo1)* is based on the approach of Saiz (2010), who considers US metropolitan statistical areas (MSAs) with populations of at least half a million. Focusing on a circle with a 50 km radius from the centre of the MSA, Saiz estimates the area of undevelopable land; which he defines as the area corresponding to steep slopes (>50%), oceans, lakes, wetlands and other water features. He views this measure of undevelopable land as reflecting original constraints on development and as being a fundamentally exogenous variable. Because we are using data for a single metropolitan area, Saiz's approach does not map perfectly into our analysis. For most LGAs in Sydney a relatively low proportion of land is undevelopable according to the measure proposed by Saiz.

A more inclusive – but possibly less exogenous – measure of unavailable land can be obtained by adding to the Saiz-measure, land within an LGA that is currently used for airports, cemeteries, reserves, recreation areas and prohibited areas. This yields a second variable *Geo2.*

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[7] Gitelman and Otto (2012) find that supply elasticity for houses increases for clusters of LGAs that are further away from the CBD.

[8] The distance from a suburb to the CBD is measured from the most significant point in a suburb, such as the largest intersection in the centre of a suburb. Distance is calculated as great circle distance, which is the shortest distance between two points on a sphere, measured along the surface of the sphere.

[9] The area of an LGA is based on its current boundaries. Where boundaries have changed in the period 1991-2012 we have tried to splice the data to obtain a consistent set of data for each LGA. The LGA with the largest area is Hawkesbury (2,783.2 sq. km) and the smallest is Hunters Hill (5.6 sq. km). The estimated supply elasticities for houses and apartments in Hawkesbury are 0.32 and 0.33 respectively, while the comparable estimates for Hunters Hill are 0.19 and 0.57.

Our third geographic variable (*Geo3*) measures the proportion of land within each LGA that can *currently* be characterized as built-up area. The forth geographic variable (*Geo4*) measures unavailable land in an LGA as the aggregate of undevelopable, reserved and built-up areas (i.e. *Geo2 + Geo3*).

4.3 Scatter-Plots

To examine the possible relationships in the data we begin our analysis by examining scatter-plots between supply elasticity and the explanatory variables.

Distance to CBD

Figure 10 plots the estimated supply elasticity for houses for an LGA against the distance of the LGA from the CBD. It is evident that there is a positive relationship between the supply elasticity for houses and the distance from the CBD[10]. Supply elasticity for houses increases with distance from the CBD. For each 10 km increase in distance from the CBD the supply elasticity for houses increases by 0.08. One notable feature of Figure 9 are the three LGAs for which the estimated supply elasticity is well above what is predicted by their respective distances from the CBD – Baulkham Hills, Liverpool and Camden.

Figure 11 shows the supply elasticity for apartments against distance from the CBD. What is apparent is that – unlike houses – the supply elasticity for apartments is unrelated to the distance of an LGA from the CBD.

Processing Time for a Development Application

Residential construction within LGAs is partially regulated though a development application (DA) process. As illustrated by Figure 12 the time taken by a Local Council to process (i.e. to make an initial decision on) a development application varies considerably across LGAs. We might expect that supply elasticity to be negatively related with the time required in processing a DA. Figures 13 and 14 plot supply elasticity for houses and apartments (respectively) against the mean number of days taken to process a DA. The scatter-plots do point to a negative relationship for both houses and apartments – higher supply elasticity is associated with lower mean processing times – although the correlation is much stronger for houses than for apartments.

Geographic Factors

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[10] Since population density declines with distance from the CBD, the supply elasticity for houses shows a negative relationship with population density. We have not presented a scatter-plot for this relationship.

One factor that is expected to influence supply elasticity is the amount of land available for housing development within a particular LGA. Figure 10 already suggests this is the case, since the supply elasticity for houses increases with distance from the CBD and it is generally the case that the size (area) of LGAs increases with distance from the CBD. However Figure 11 indicates that land availability is more likely to affect the supply elasticity for houses rather than for apartments. Apartments use less land per square metre of housing space and new apartments can be supplied through urban re-development (i.e. replacing existing houses (or old apartments) by new one or by replacing industrial areas with new apartments). In inner-city areas of Sydney LGAs it is likely to be relatively costly to significantly increase the supply of new houses, due to a lack undeveloped land available for new construction.
Figure 15 presents a scatter-plot of supply elasticity for houses against Saiz's measure of undevelopable land in each LGA. Note that the share of undevelopable land in Sydney's LGAs is relatively low (less than 10 percent) and the scatter-plot indicates a weak positive (rather than the expected negative) relationship. An attractive feature of Saiz's measure of undevelopable land is its exogeneity, in that steep slopes and natural water features are likely to be fundamental influences on the cost of development. The remaining three measures of undevelopable land all include land, which, while it may not be currently available for housing development, is not undevelopable due to its physical characteristics, but because it is currently being used for some other purpose (possibly including housing). *Geo2* adds reserved land to Saiz's measure. However despite its more comprehensive status, Figure 16 indicates that there is also a positive correlation between supply elasticity and *Geo2*.

Figure 17 plots supply elasticity for houses against the share of built-up areas within each LGA (*Geo3*). In this case we do see a negative relationship, with lower supply elasticity in LGAs which are relatively more built-up. This negative correlation is also evident in Figure 18 where potentially unavailable land is measured by the sum (*Geo2 + Geo3)*.

4.4 Determinants of Supply Elasticity

Estimates of the cross-section model for supply elasticity are reported in Tables 2 and 3, for houses and apartments respectively. The explanatory variables included in the model are distance from the CBD; population density; the time taken to process a DA and one of the four possible measures of undevelopable land.

The results in Table 2 indicate that around 60 to 80 percent of the variation in the supply elasticity of houses across Sydney LGAs is explained by the available regressors. Across all of the specifications, the three variables that are most consistently correlated with estimated supply elasticity for houses, in an LGA; are the mean-time taken to approve a DA, population density and the quantity of undevelopable land. The distance of an LGA from the CBD is not found to be statistically significant influence on supply elasticity, when it is included with the other regressors.

Model (1) includes Saiz's measure of undevelopable land, and while this variable does have a negative effect on supply elasticity, the effect is not estimated very precisely. Nevertheless, it is interesting that geographic features such as natural water-bodies and land gradient do have some influence on the supply elasticity for houses across Sydney. In model (2) use of a broader measure of undevelopable land (which includes certain types of reserved land) yields a negative and highly significant coefficient estimate. In effect the higher the proportion of undevelopable or reserved land in an LGA; the lower is the supply elasticity for houses.

In model (3) we use the proportion of an LGA that is classified as build-up, as a proxy for land that is difficult or costly to use for houses. The share of build-up land has a significantly negative effect on the supply elasticity for houses, although including built-up area in the model results in population density becoming insignificant. Model (4) uses our broadest measure of undevelopable land (*Geo4*) and implies that the supply elasticity for houses is largest in LGAs with low population densities, fast processing times for DAs and relatively large areas of potentially developable land. Model (5) is similar to (4) except that mean DA processing time is replaced by the median.

We can visualize the fit of the cross-section model for houses by comparing the fitted values for model (4) with the estimated supply elasticities, see Figure 19. The overall cross-section variation in the supply elasticity estimates is well-explained by the variables in the model. The two LGAs with the largest (absolute) residuals are Camden where the model under-predicts the supply elasticity (0.74 verses 0.96) and Penrith where the model over-predicts (0.63 verses 0.36). Table 4 presents a comparison of the supply elasticity estimates for Camden and Penrith, along with their main characteristics. These two LGAs have broadly similar characteristics; although Camden has a lower population density than Penrith (8 verses 12 people per square kilometer) and also a somewhat larger proportion of developable land (87 verses 74 percent). What is interesting is that while Camden has the larger supply elasticity for houses (0.96 verses 0.36); Penrith has the larger supply elasticity for apartments (0.53 verses 0.18). In fact Camden has one of the lowest apartments supply elasticity estimates across all of Sydney's LGAs.

Turing to the elasticity of supply for apartments, it is evident from Table 3 that none of the potential explanatory variables have any significant relationship with elasticity. Variations in supply elasticity for apartments across LGAs in Sydney appear to be essentially random.

Finally we examine whether there is a correlation between the long-run price of housing in an LGA and the estimated supply elasticity. For houses there is a strong correlation between the estimated supply elasticity and the average real house price in an LGA. Figure 20 plots the log of average real house prices (for the period 1991-2012) against the inverse of the estimated supply elasticity for each LGA. In general LGAs with more inelastic supply responses have higher priced houses. Figure 21 indicates that no such relationship holds for apartments.

5. Conclusion

This paper presents estimates of the supply elasticity for houses and apartments for the 43 LGAs in metropolitan Sydney. Using data for the period 1991-2012 we obtain sensible (non-negative) estimates, expect in one case. For the majority of LGAs the supply elasticity of apartments is larger than for houses. On average a uniform five percent increase in real residential property prices in Sydney would – other things equal – increase the stock of houses by one percent and the stock of apartments by four percent.

In modeling the variation in supply elasticity across LGAs we find no useful explanatory variables for differences in the estimated supply elasticity for apartments. In the case of houses, we find variation in supply elasticity at the LGA-level is associated with: population densities; processing speed for development approvals and the availability of developable land.

The primary objective of this paper is to present some empirical evidence on housing supply elasticity in Sydney at a dis-aggregated level. A natural extension would be to develop a structural model of supply elasticity using an urban development model of the type used in Saiz (2010) and Kulish, Richards and Gillitzer (2012).

References

Ball, M., Meen, G. and Nygaard, C. 2010, "Housing supply price elasticities revisited: evidence from international, national, local and company data," *Journal of Housing Economics*, 19, 255-268.

Gitelman, E. and Otto, G. 2012, "Supply elasticity estimates for the Sydney housing market," *Australian Economic Review,* 45(2), 176-190

Green, R.K., Malpezzi, S. and Mayo, S.K. 2005, "Metropolitan-specific estimates of the price elasticity of supply of housing and their sources," *American Economic Review*, 95(2), 334-339.

Kulish, M., Richards, A. and Gillitzer, C. 2012, "Urban structure and housing prices: some evidence from Australian cities," *Economic Record,* 88, September, 303-322.

Newey, W. and West, K. D. (1987), "A simple, positive semi-definite, heteroskedasticity and autocorrelation-consistent covariance matrix," *Econometrica*, 55(3), 703–708.

Saiz, A. 2010, "The geographic determinants of housing supply," *Quarterly Journal of Economics*, 125(3), 1253-1296.

Sánchez, A.C. and Johansson, A. 2011, "The price responsiveness of housing supply in OECD countries," OECD Economics Department Working Paper, No. 837.

Stock, J.H. and Yogo, M. 2002, "Testing for weak instruments in linear IV regression," NBER Technical Working Paper 284.

White, H. 1980, "A heteroskedasticity-consistent covariance matrix estimator and direct test for heteroskedasticity," *Econometrica*, 48, 817-838.

Table 1: Sydney Local Government Areas

1. Ashfield	16. Holroyd	30. Penrith
2. Auburn	17. Hornsby	31. Pittwater
3. Bankstown	18. Hunters Hill	32. Randwick
4. Baulkham Hills	19. Hurstville	33. Rockdale
5. Blacktown	20. Kogarah	34. Ryde
6. Blue Mountains	21. Ku-ring-gai	35. Strathfield
7. Botany	22. Lane Cove	36. Sutherland
8. Burwood	23. Leichhardt	37. Sydney
9. Camden	24. Liverpool	38. Warringah
10. Campbelltown	25. Manly	39. Waverley
11. Canada Bay	26. Marrickville	40. Willoughby
12. Canterbury	27. Mosman	41. Woollahra
13. Fairfield	28. North Sydney	42. Wollondilly
14. Gosford	29. Parramatta	43. Wyong
15. Hawkesbury		

Table 2: Models of Supply Elasticity for Houses

	Dependent Variable:	*Supply Elasticity for Houses*			
	(1)	(2)	(3)	(4)	(5)
Geo1	-3.2682	-	-	-	-
	(1.6824)				
Geo2	-	**-0.5592**	-	-	-
		(0.1893)			
Geo3	-	-	**-0.3378**	-	-
			(0.1303)		
Geo4	-	-	-	**-0.6324**	**-0.6681**
				(0.1192)	(0.1249)
CBD Distance	0.0179	0.0042	0.0329	-0.0195	-0.0340
	(0.0356)	(0.0272)	(0.0285)	(0.0181)	(0.0256)
Pop Density	**-0.0892**	**-0.1351**	0.0194	**-0.0293**	**-0.0336**
	(0.0388)	(0.0389)	(0.0283)	(0.0131)	(0.0135)
Mean DA	**-0.3179**	**-0.1785**	**-0.3302**	**-0.1252**	-
	(0.0967)	(0.0647)	(0.1048)	(0.0391)	
Med DA	-	-	-	-	-0.0712
					(0.0486)
Constant	**2.2096**	**2.0632**	**1.5842**	**1.5197**	**1.3691**
	(0.6076)	(0.4210)	(0.4592)	(0.2351)	(0.3074)
$\bar{R}^2$	0.608	0.677	0.619	0.809	0.798

Notes: The numbers in parentheses are heteroskedasticity-robust standard errors (White 1980). Significant coefficients at the five percent level are highlighted in bold face.

Table 3: Models of Supply Elasticity for Apartments

	Dependent Variable:	*Supply Elasticity for Apartments*			
	(1)	(2)	(3)	(4)	(5)
Geo1	-10.3299	-	-	-	-
	(10.5649)				
Geo2	-	-1.8742	-	-	-
		(1.7832)			
Geo3	-	-	-0.0517	-	-
			(0.9353)		
Geo4	-	-	-	-1.1886	-1.1384
				(1.6360)	(1.4999)
CBD Distance	0.0210	-0.0298	0.0981	-0.0174	-0.0407
	(0.2290)	(0.2839)	(0.2189)	(0.2996)	(0.3499)
Pop Density	-0.0753	-0.2379	0.0787	0.0958	0.0954
	(0.2123)	(0.3410)	(0.1562)	(0.1073)	(0.1093)
Mean DA	-0.3630	0.1097	-0.4521	-0.0379	-
	(0.4572)	(0.7263)	(0.4723)	(0.6771)	
Med DA	-	-	-	-	-0.0036
					(0.6228)
Constant	2.9835	2.5546	1.9173	1.2734	1.1449
	(3.2747)	(3.5942)	(2.5189)	(2.9356)	(3.4544)
$\bar{R}^2$	-0.049	0.003	-0.080	-0.025	-0.025

Notes: The numbers in parentheses are heteroskedasticity-robust standard errors (White 1980). Significant coefficients at the five percent level are highlighted in bold face.

Table 4: Comparison of Penrith and Camden LGAs

	Elasticity		*Characteristics*				
	House	Apartment	Med DA (days)	CBD dist (kms)	Pop Den (pop/km^2)	Saiz_plus (%)	Built-up (%)
Penrith	0.36	0.53	45	45	429	10	16
Camden	0.96	0.18	40	48	214	4	9

Figure 1: F-statistic for Instrument Quality

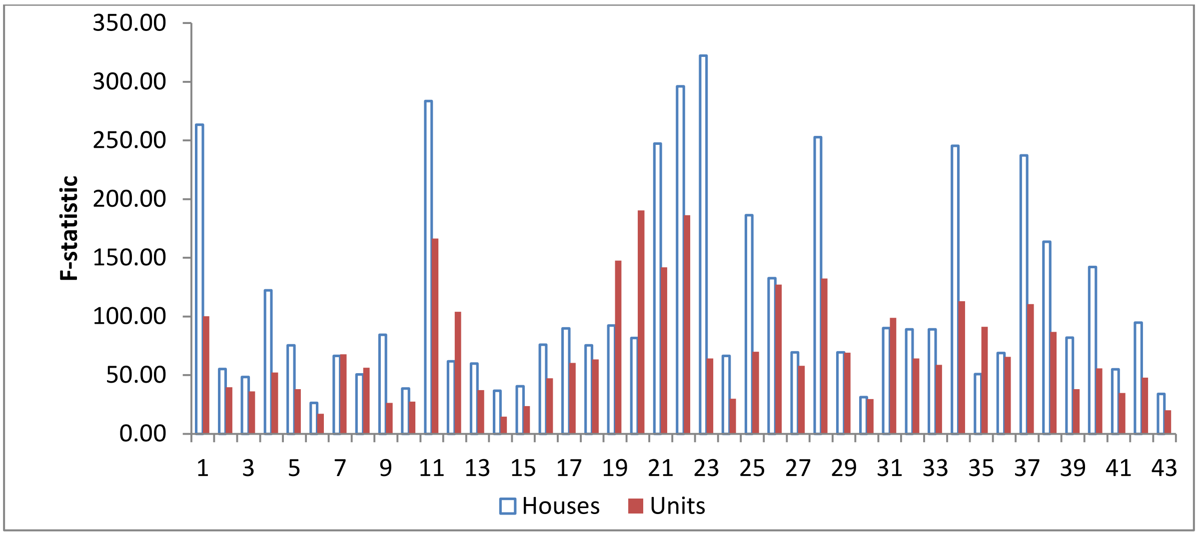


Figure 2: Estimates of Supply Elasticity for Houses by LGA

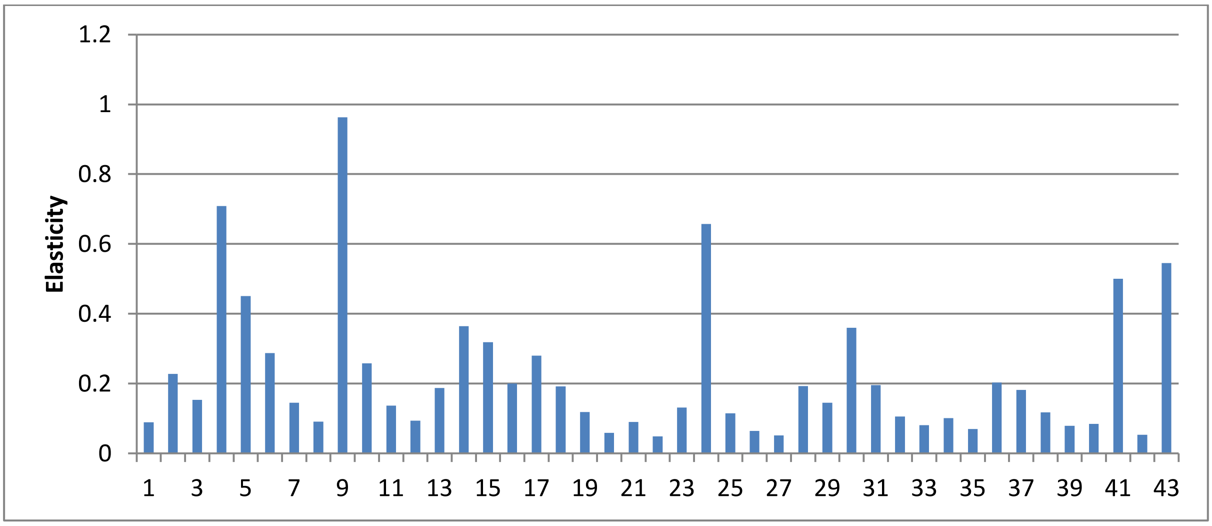


Figure 3: Estimates of Supply Elasticity for Apartments by LGA

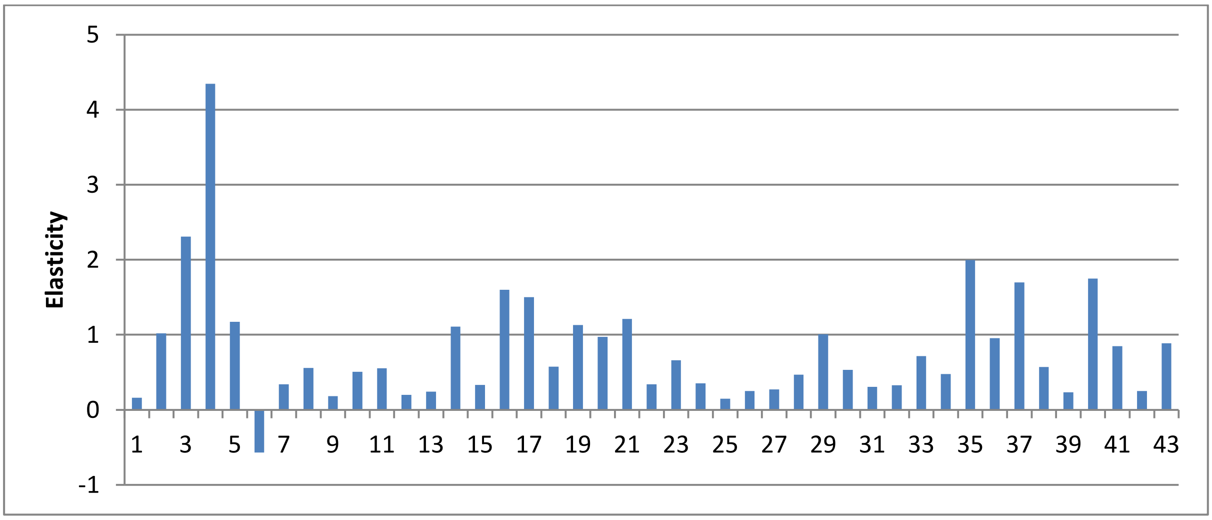


Figure 4: Apartment Prices and Quantities for Blue Mountains

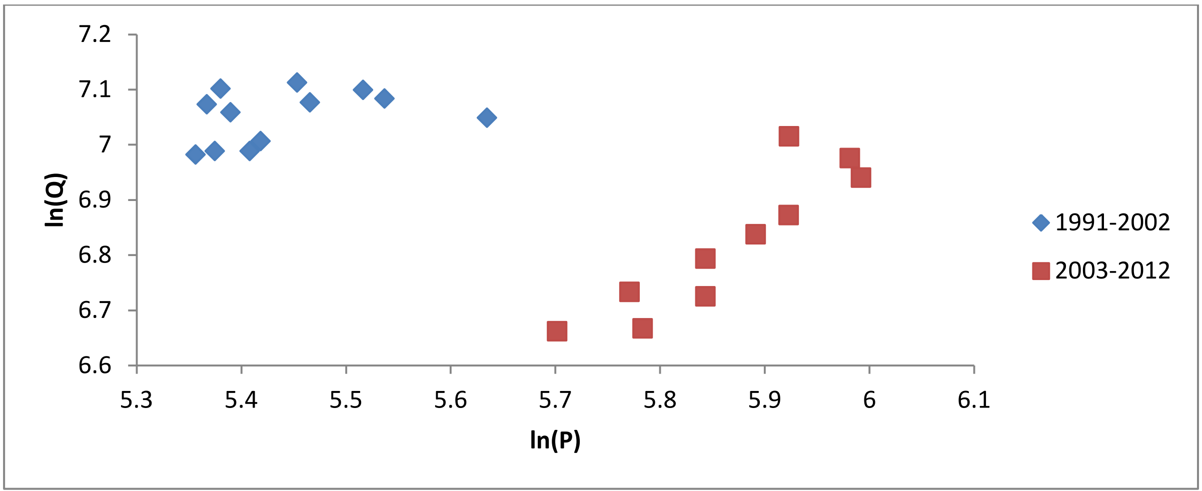


Figure 5: F-statistics for Bounds Test – Houses

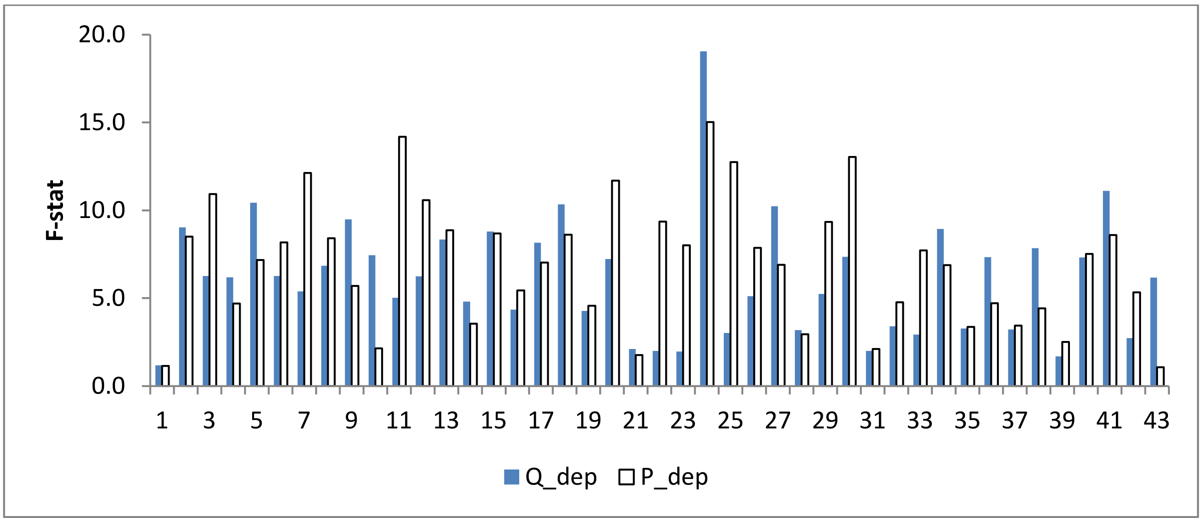


Figure 6: F-statistics for Bounds Test – Apartments

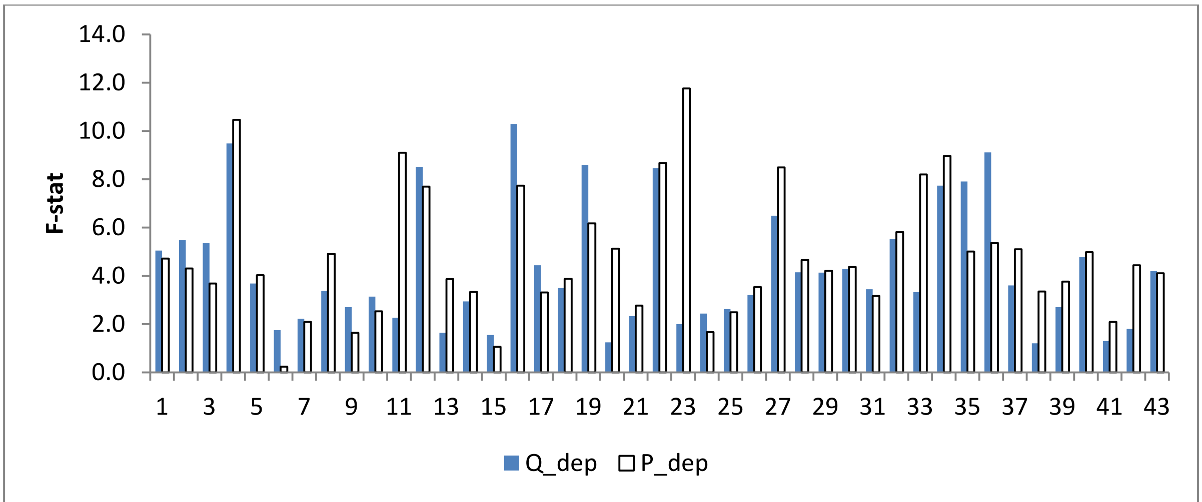


Figure 7: Correlation between IV and ARDL Estimates – Houses

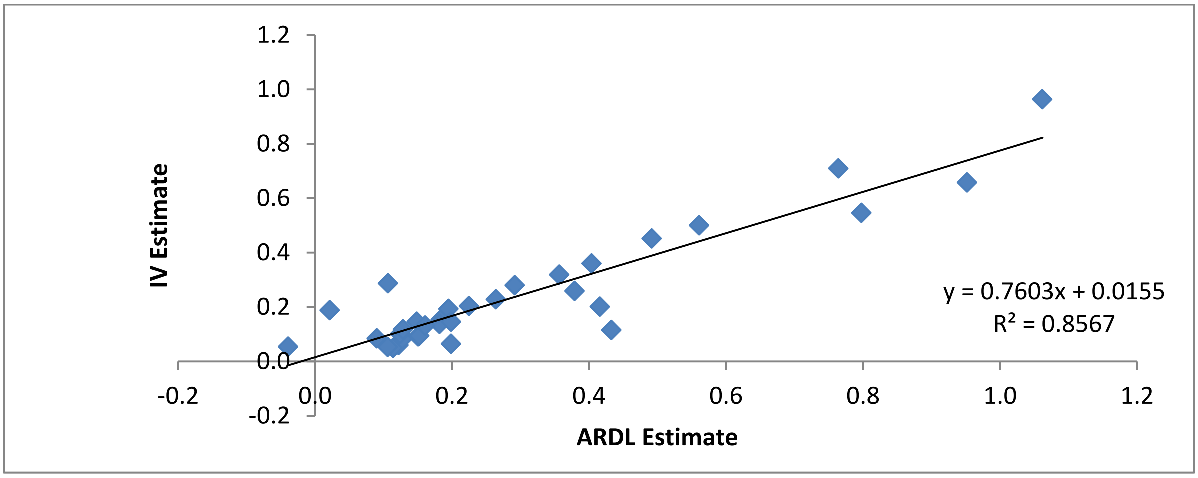


Figure 8: Correlation between IV and ARDL Estimates – Apartments

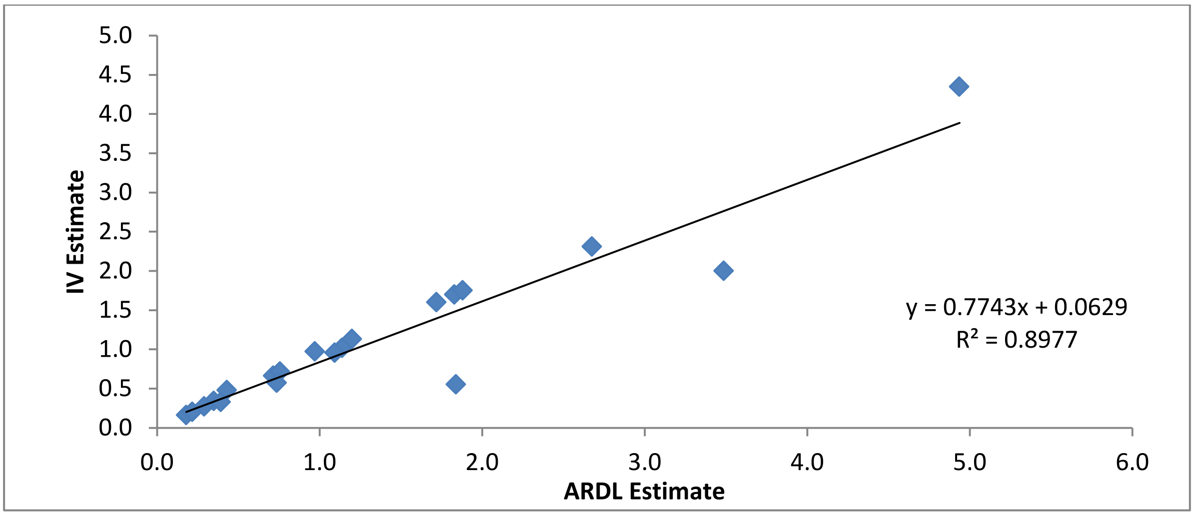


Figure 9: Density Functions of Supply Elasticity Estimates for LGAs

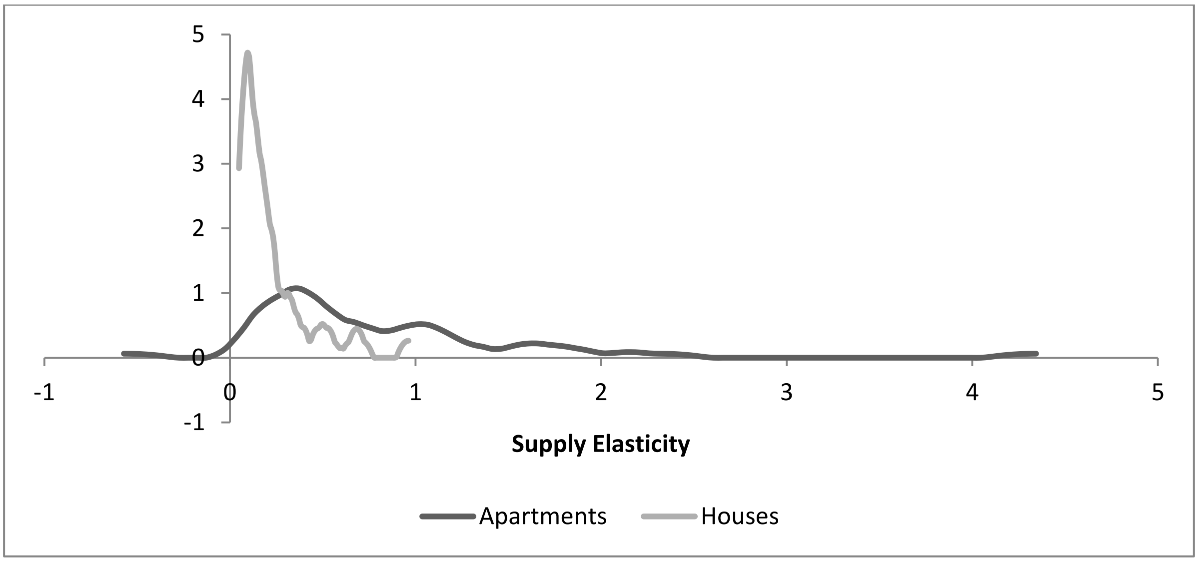


Figure 10: Supply Elasticity for Houses and Distance to CBD

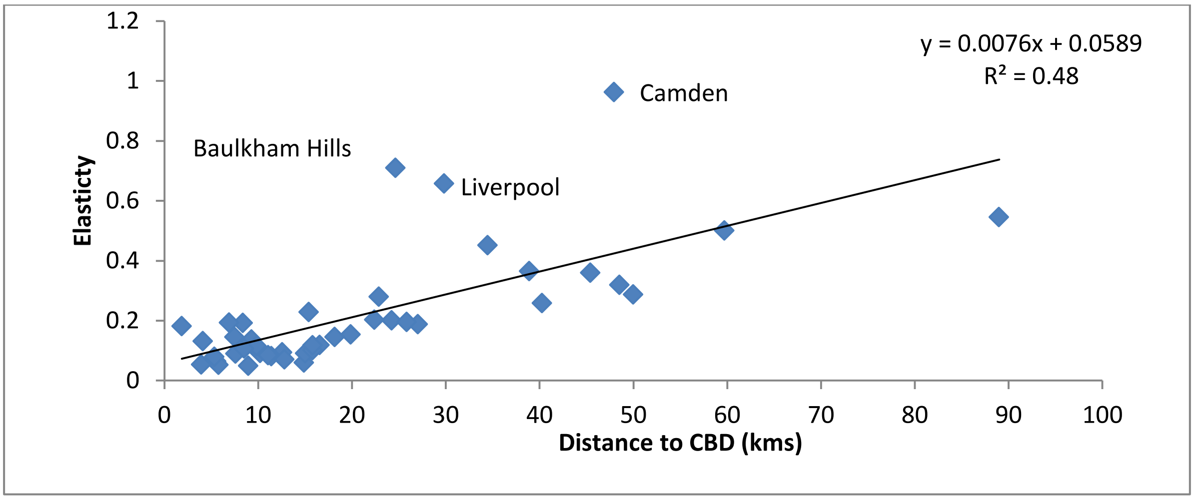


Figure 11: Supply Elasticity for Apartments and Distance to CBD

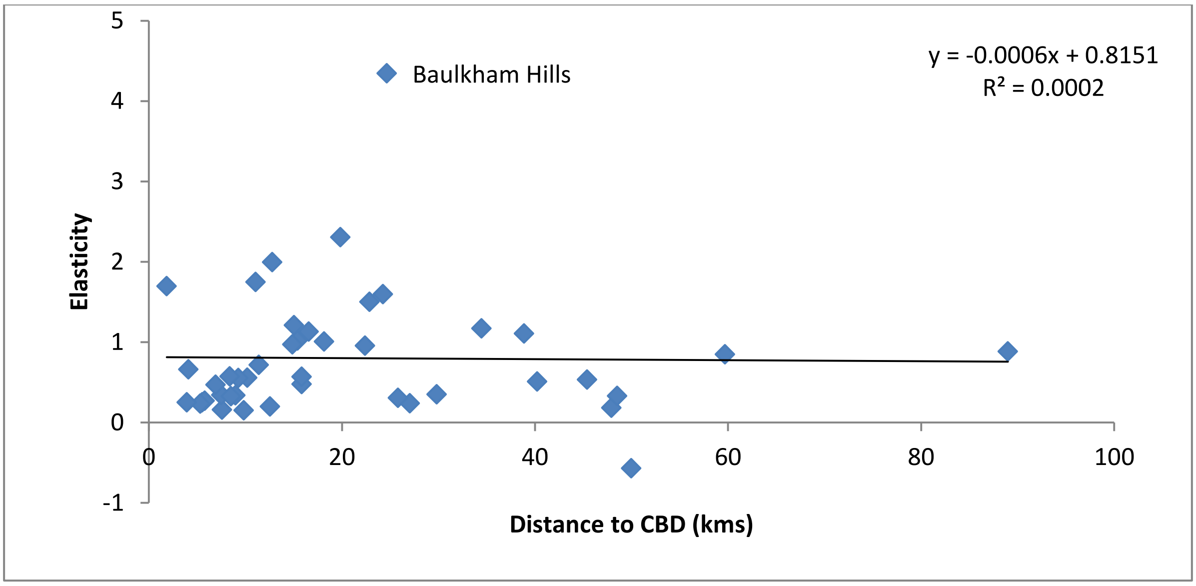


Figure 12: Mean Time to Decision on DA

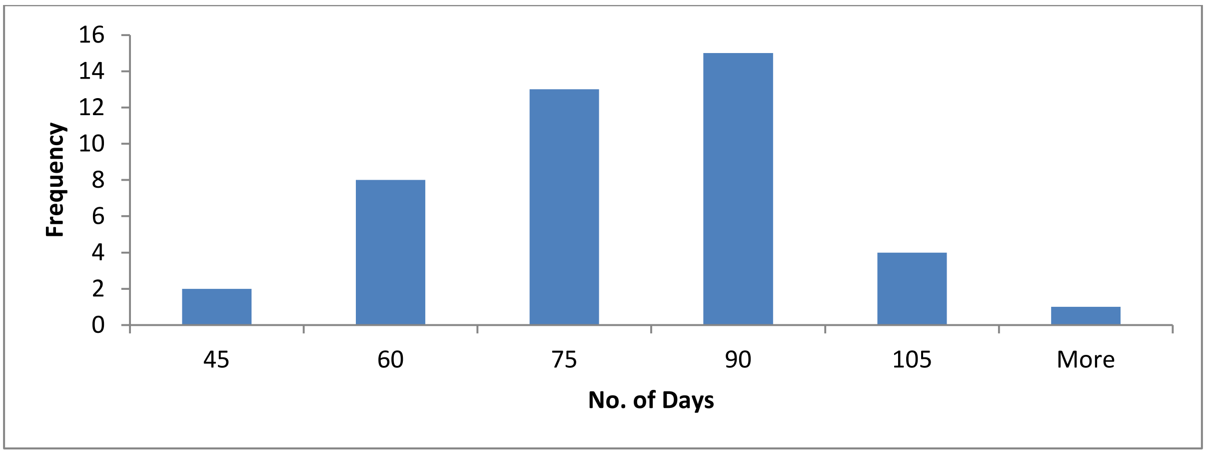


Figure 13: Supply Elasticity for Houses and DA Approval Times

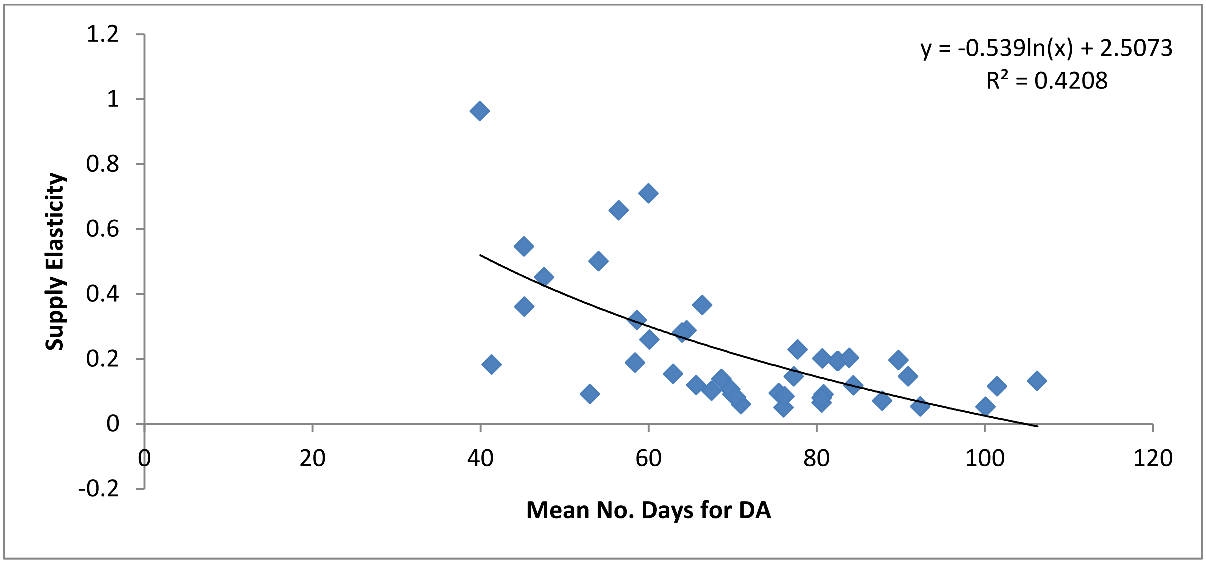


Figure 14: Supply Elasticity for Apartments and DA Approval Times

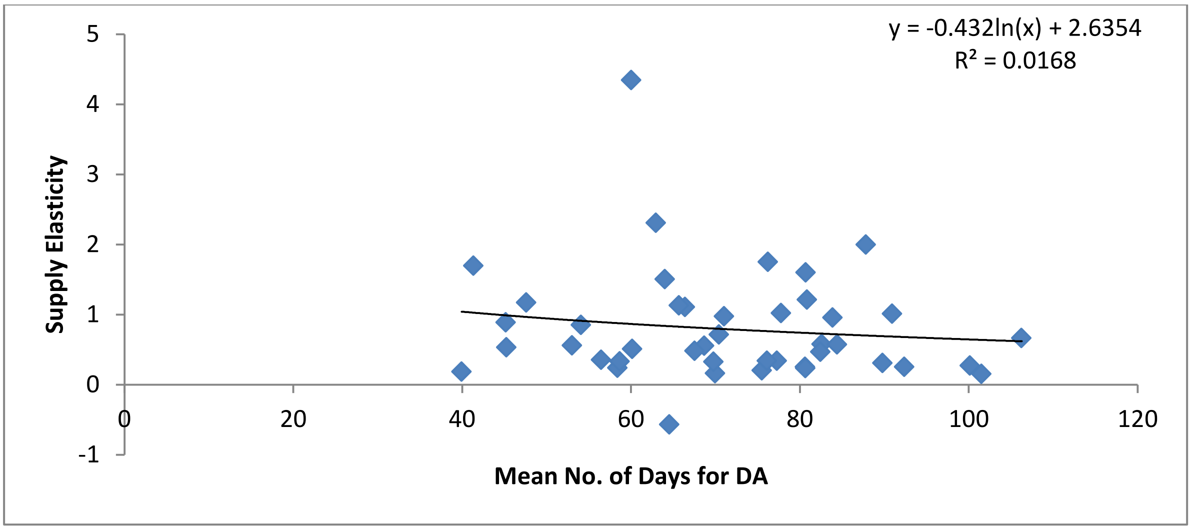


Figure 15: Supply Elasticity for Houses and Saiz's Measure of Undevelopable Land

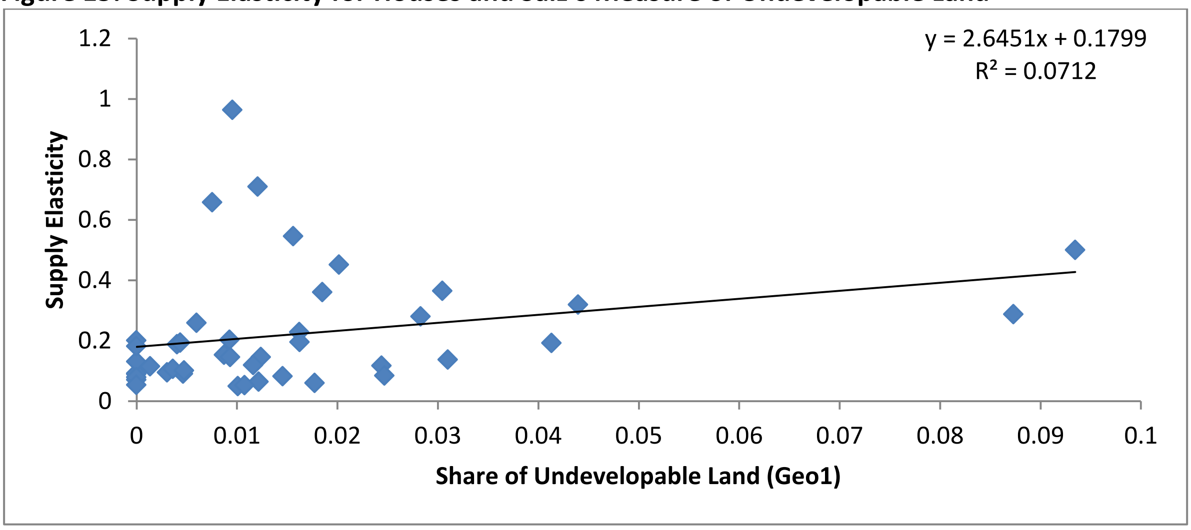


Figure 16: Supply Elasticity for Houses and Reserved and Undevelopable Land

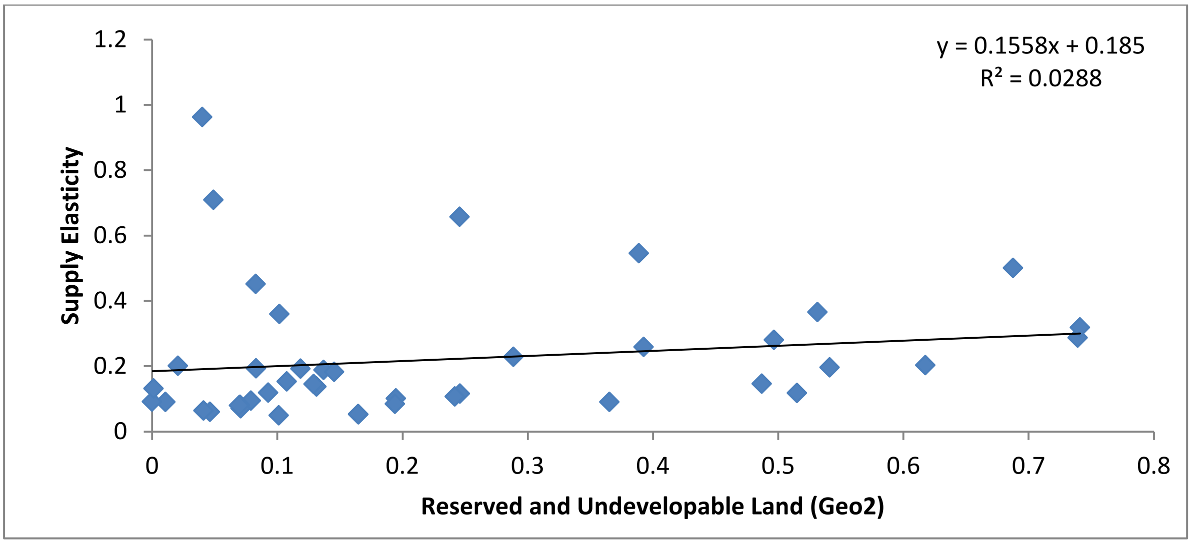


Figure 17: Supply Elasticity for Houses and Built-up Area

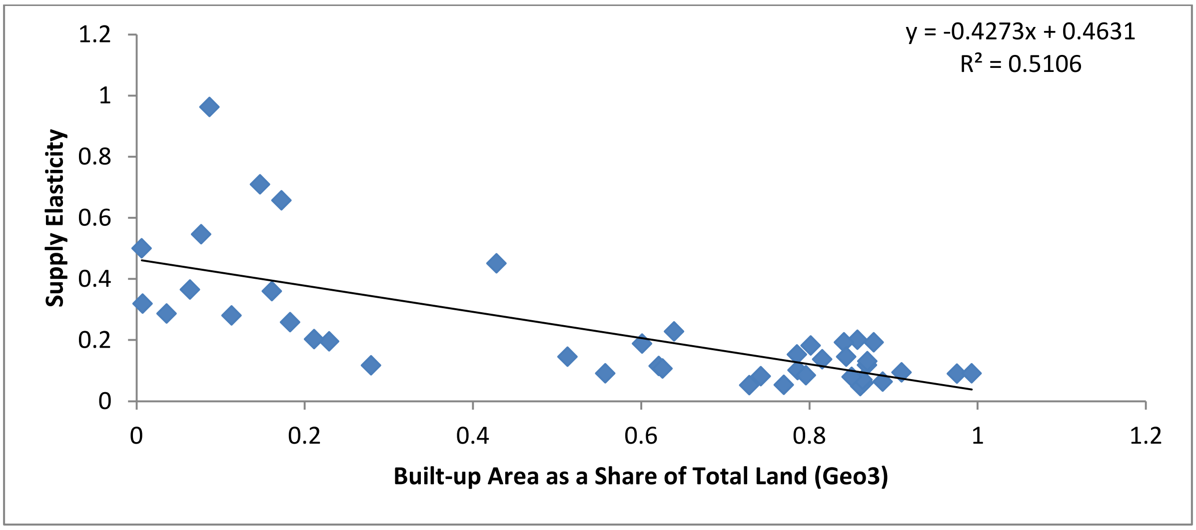


Figure 18: Supply Elasticity for Houses and Potentially Unavailable Land

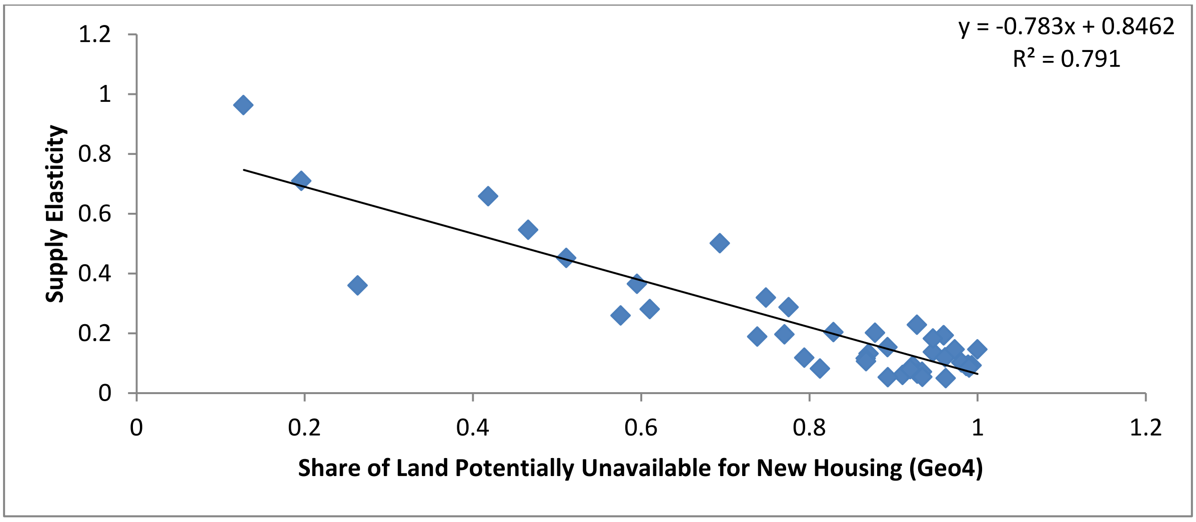


Figure 19: Actual and Fitted Supply Elasticity for Houses

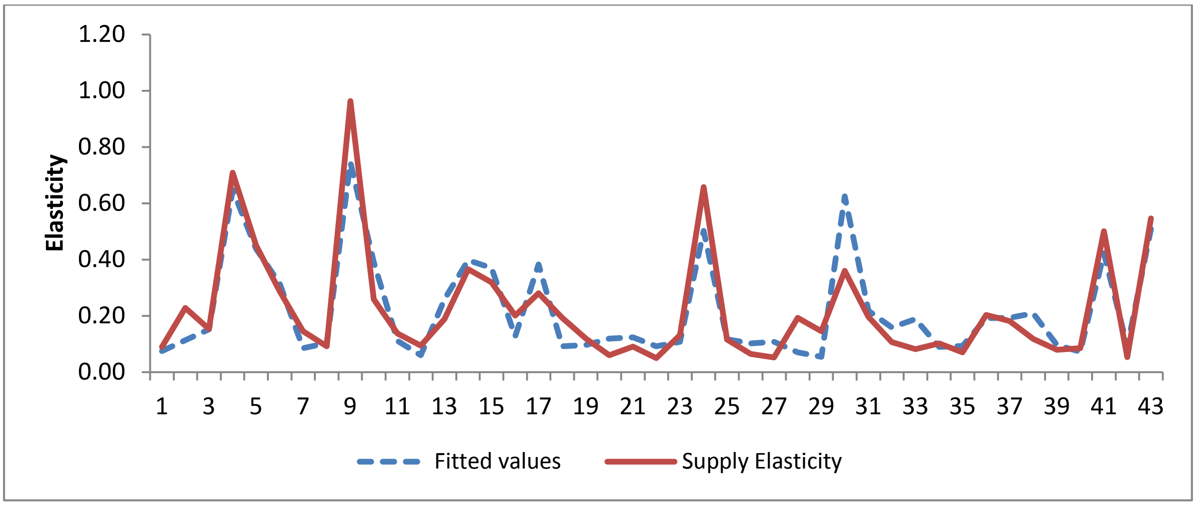


Figure 20: Estimated Supply Elasticities and Real House Prices

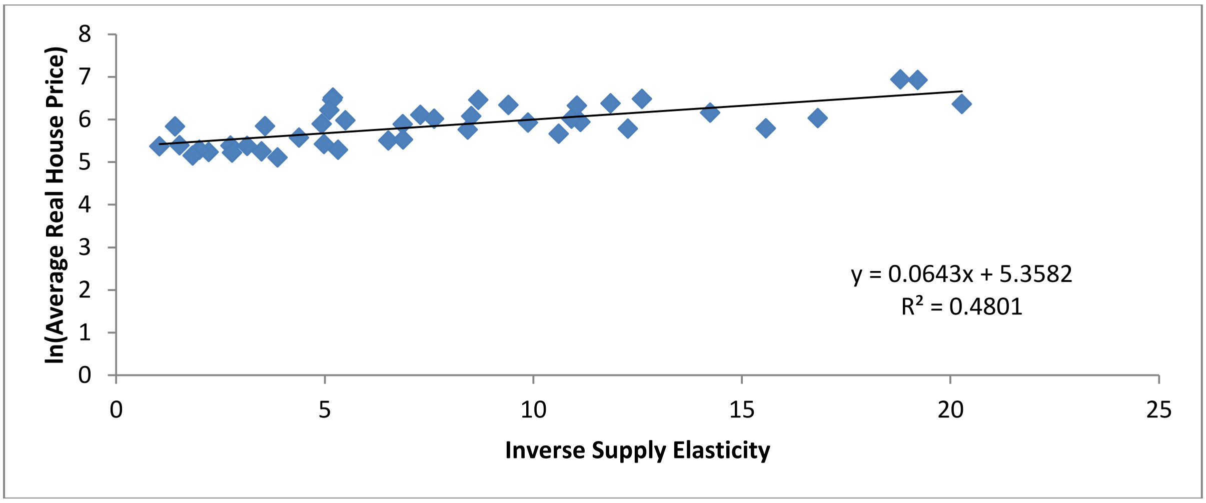
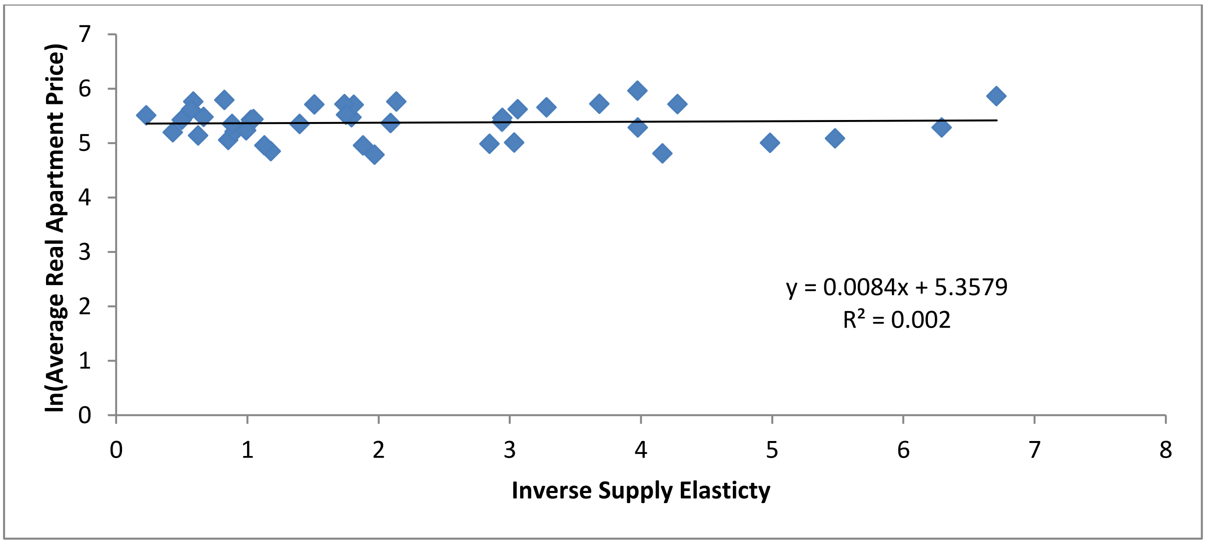


Figure 21: Estimated Supply Elasticities and Real Apartment Prices



Appendix: Additional Results

Table A1: Supply Elasticity Estimates and Standard Errors – Instrumental Variables

	Houses		Apartments	
LGA	Elasticity	Std Error	Elasticity	Std Error
Ashfield	0.09	0.015	0.16	0.031
Auburn	0.23	0.032	1.02	0.151
Bankstown	0.15	0.017	2.31	0.252
Baulkham Hills	0.71	0.049	4.34	0.367
Blacktown	0.45	0.063	1.17	0.268
Blue Mountains	0.29	0.038	-0.57	0.247
Botany	0.15	0.008	0.34	0.075
Burwood	0.09	0.019	0.56	0.037
Camden	0.96	0.079	0.18	0.208
Campbelltown	0.26	0.031	0.51	0.272
Canada Bay	0.14	0.016	0.55	0.091
Canterbury	0.09	0.016	0.20	0.027
Fairfield	0.19	0.026	0.24	0.029
Gosford	0.36	0.040	1.11	0.317
Hawkesbury	0.32	0.044	0.33	0.076
Holroyd	0.20	0.039	1.60	0.211
Hornsby	0.28	0.033	1.50	0.136
Hunters Hill	0.19	0.016	0.57	0.089
Hurstville	0.12	0.013	1.13	0.061
Kogarah	0.06	0.013	0.97	0.071
Ku-ring-gai	0.09	0.007	1.21	0.308
Lane Cove	0.05	0.010	0.34	0.041
Leichhardt	0.13	0.011	0.66	0.056
Liverpool	0.66	0.052	0.35	0.106
Manly	0.12	0.021	0.15	0.037
Marrickville	0.06	0.016	0.25	0.031
Mosman	0.05	0.010	0.27	0.022
North Sydney	0.19	0.018	0.47	0.043
Parramatta	0.15	0.017	1.01	0.164
Penrith	0.36	0.053	0.53	0.106
Pittwater	0.20	0.030	0.30	0.074
Randwick	0.11	0.012	0.33	0.041
Rockdale	0.08	0.015	0.71	0.065
Ryde	0.10	0.006	0.48	0.063
Strathfield	0.07	0.022	2.00	0.456
Sutherland	0.20	0.017	0.96	0.077
Sydney	0.18	0.042	1.70	0.129
Warringah	0.12	0.006	0.57	0.079
Waverley	0.08	0.019	0.23	0.045
Willoughby	0.08	0.003	1.75	0.114
Woollahra	0.50	0.052	0.85	0.316
Wollondilly	0.05	0.020	0.25	0.044
Wyong	0.55	0.070	0.88	0.277

Notes: Instruments used are real per-capita income, population and the real interest rate. Standard errors are robust to serial correlation (lags=5) and heteroskedasticity (Newey and West, 1987).

Table A2: ARDL Bounds Test and Long-run Elasticity – Houses

	Model (5a)		Model (5b)		ARDL
LGA	F-stat	$\frac{\hat{\delta}_{QP}}{\hat{\delta}_{QQ}}$	F-stat	$\frac{\hat{\delta}_{PP}}{\hat{\delta}_{PQ}}$	LR Elasticity
Ashfield	1.17	-0.16	1.13	0.00	na
Auburn	9.02	0.26	8.51	0.26	0.26
Bankstown	6.25	0.17	10.92	0.18	0.18
Baulkham Hills	6.19	0.76	4.70	0.71	0.76
Blacktown	10.42	0.49	7.17	0.32	0.49
Blue Mountains	6.26	0.32	8.17	0.11	0.11
Botany	5.39	0.16	12.13	0.15	0.15
Burwood	6.84	0.15	8.41	0.15	0.15
Camden	9.48	1.06	5.69	1.10	1.06
Campbelltown	7.45	0.38	2.14	0.16	0.38
Canada Bay	5.02	0.19	14.18	0.18	0.18
Canterbury	6.23	0.16	10.57	0.15	0.15
Fairfield	8.33	0.21	8.86	0.02	0.02
Gosford	4.81	0.51	3.54	0.20	na
Hawkesbury	8.79	0.36	8.68	0.22	0.36
Holroyd	4.35	0.25	5.43	0.42	0.42
Hornsby	8.14	0.29	7.02	0.26	0.29
Hunters Hill	10.35	0.19	8.61	0.19	0.19
Hurstville	4.27	0.15	4.56	0.14	na
Kogarah	7.21	0.10	11.68	0.12	0.12
Ku-ring-gai	2.10	0.10	1.76	0.18	na
Lane Cove	1.99	0.13	9.35	0.11	0.11
Leichhardt	1.97	0.18	8.01	0.16	0.16
Liverpool	19.04	0.95	15.02	1.08	0.95
Manly	3.01	-2.67	12.74	0.43	0.43
Marrickville	5.11	0.17	7.86	0.20	0.20
Mosman	10.23	0.11	6.90	0.11	0.11
North Sydney	3.18	0.25	2.94	0.27	na
Parramatta	5.24	0.16	9.34	0.20	0.20
Penrith	7.36	0.40	13.03	0.11	0.40
Pittwater	1.99	0.45	2.11	0.36	na
Randwick	3.40	0.15	4.76	0.13	na
Rockdale	2.92	0.14	7.72	0.13	0.13
Ryde	8.93	0.12	6.88	0.12	0.12
Strathfield	3.28	0.12	3.36	0.14	na
Sutherland	7.33	0.23	4.71	0.19	0.23
Sydney	3.21	0.32	3.43	0.41	na
Warringah	7.85	0.13	4.41	0.12	0.13
Waverley	1.69	-1.67	2.51	0.21	na
Willoughby	7.32	0.09	7.52	0.09	0.09
Woollahra	11.11	0.56	8.59	0.41	0.56
Wollondilly	2.72	0.02	5.34	-0.04	-0.04
Wyong	6.16	0.80	1.08	0.34	0.80

Notes: Critical values at a 5% level of significance for the bounds test are [4.94, 5.73]. F-statistics below 4.94 imply that we cannot reject the null hypothesis of no levels relationship between price and quantity. ARDL elasticity estimate corresponds to model with the maximum F-statistic.

Table A3: ARDL Bounds Test and Long-run Elasticity – Apartments

	Model (5a)		Model (5b)		ARDL
LGA	F-stat	$\frac{\hat{\delta}_{QP}}{\hat{\delta}_{QQ}}$	F-stat	$\frac{\hat{\delta}_{PP}}{\hat{\delta}_{PQ}}$	LR Elasticity
Ashfield	5.05	0.18	4.71	0.18	0.18
Auburn	5.48	1.14	4.29	1.09	1.14
Bankstown	5.36	2.68	3.68	2.26	2.68
Baulkham Hills	9.48	5.03	10.46	4.94	4.94
Blacktown	3.68	1.60	4.03	1.50	na
Blue Mountains	1.74	-2.27	0.23	-1.66	na
Botany	2.22	0.39	2.08	0.33	na
Burwood	3.37	0.59	4.91	0.59	na
Camden	2.70	-1.23	1.64	10.87	na
Campbelltown	3.14	0.76	2.53	0.76	na
Canada Bay	2.26	2.20	9.10	1.84	1.84
Canterbury	8.51	0.22	7.69	0.23	0.22
Fairfield	1.64	0.25	3.86	0.25	na
Gosford	2.94	2.07	3.33	1.17	na
Hawkesbury	1.54	-0.18	1.06	1.18	na
Holroyd	10.29	1.72	7.74	1.67	1.72
Hornsby	4.43	1.76	3.30	1.58	na
Hunters Hill	3.49	0.77	3.88	0.68	na
Hurstville	8.59	1.20	6.16	1.20	1.20
Kogarah	1.25	1.10	5.12	1.05	0.97
Ku-ring-gai	2.32	2.05	2.76	2.44	na
Lane Cove	8.46	0.35	8.67	0.35	0.35
Leichhardt	2.00	1.20	11.75	0.72	0.72
Liverpool	2.43	0.94	1.67	1.10	na
Manly	2.62	0.39	2.49	0.39	na
Marrickville	3.20	0.31	3.53	0.34	na
Mosman	6.48	0.31	8.48	0.29	0.29
North Sydney	4.15	0.55	4.66	0.54	na
Parramatta	4.12	1.34	4.20	1.42	na
Penrith	4.28	1.02	4.37	1.17	na
Pittwater	3.43	0.48	3.16	0.50	na
Randwick	5.52	0.39	5.81	0.39	0.39
Rockdale	3.33	0.77	8.20	0.76	0.76
Ryde	7.73	0.47	8.96	0.43	0.43
Strathfield	7.91	3.49	5.00	3.52	3.49
Sutherland	9.11	1.09	5.37	0.99	1.09
Sydney	3.60	1.97	5.10	1.83	1.83
Warringah	1.20	1.67	3.35	1.01	0.74
Waverley	2.70	0.41	3.76	0.52	na
Willoughby	4.78	1.93	4.97	1.88	1.88
Woollahra	1.30	1.09	2.09	0.77	na
Wollondilly	1.79	0.32	4.43	0.30	na
Wyong	4.19	-3.02	4.10	-1.56	na

Notes: Critical values at a 5% level of significance for the bounds test are [4.94, 5.73]. F-statistics below 4.94 imply that we cannot reject the null hypothesis of no levels relationship between price and quantity. ARDL elasticity estimate corresponds to model with the maximum F-statistic.

Data Appendix

Property Prices

Median prices for LGAs are sourced from the quarterly Rent and Sales Reports published by Housing NSW.

http://www.housing.nsw.gov.au/About+Us/Reports+Plans+and+Papers/Rent+and+Sales+Reports/

Dwelling Stocks

The quantity of residential property is measured by the *number* of private residential properties in each of the 43 LGAs in metropolitan Sydney. For each LGA we construct an annual series for the stock of residential properties at end-June from 1991 to 2012. For the years 1991, 1996, 2001, 2006 and 2011, data from the relevant Census is used. To interpolate estimates for the inter-censual years we use data on the number of housing permits. Source: Regional Statistics Profiles for New South Wales, 1992-2003 and Australian National Regional Profile, 2004-2012.

In the Census, private residential dwellings are classified into three main categories:

(i) separate house;

(ii) semi-detached, row or terrace house or townhouse; and

(iii) flat, unit or apartment.

In the Regional Profile data there are two classifications for permits data:

(a) a house is defined as a detached or a semi-detached building, consisting of one residential unit and primarily used for long term residential purposes; and

(b) a dwelling unit is defined as a self-contained suite of rooms, including cooking and bathing facilities and intended for long-term residential use[11].

To ensure consistency between the two data sources, housing stock data in categories (i) and (ii) of the Census are combined and are counted as houses, while dwelling units belonging to (iii) or (b) are counted as apartments.

There are some potential difficulties with use of the permits data to interpolate the Census data on housing stocks. Not all housing permits that are issued are necessarily converted into completions and result in the construction of a new property. In some cases an existing property is demolished and replaced with one (or more) new residences. Also housing approvals will include approvals for

[11] Regardless of whether they are self-contained or not, units within buildings offering institutional care (e.g. hospital) or temporary accommodation (e.g. motels, hostels and holiday apartments) are not defined as dwelling units. Such units are included in non-residential building approvals.

renovations to existing residential buildings (and conversions of a non-residential building to a residential building.) Finally there is a timing issue in that a housing approval recorded in one year may not results in the completion of a new residence until a later year.

We can gauge an indication of the extent to which the approvals figures are a good indication of longer-term new constructions by comparing the change in the stock of houses (apartments) between two censuses (say 1996 and 1991) with the sum of approvals between the two censuses. We summarize these results in Figures A1 and A2.

Figure A1: Approvals and Outcomes for Houses

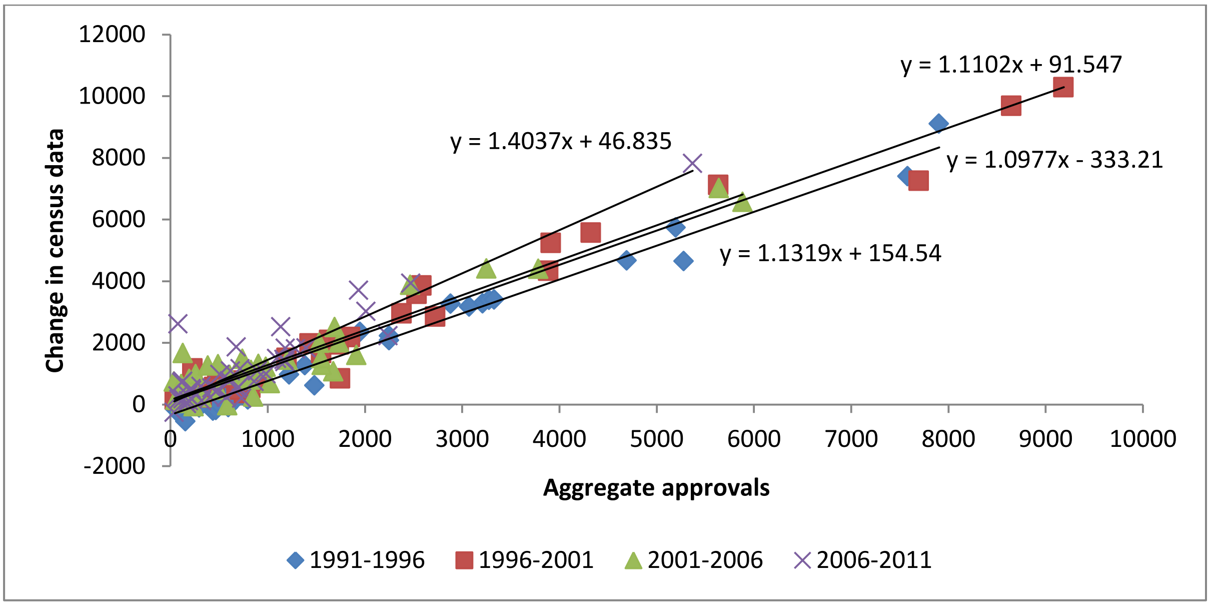
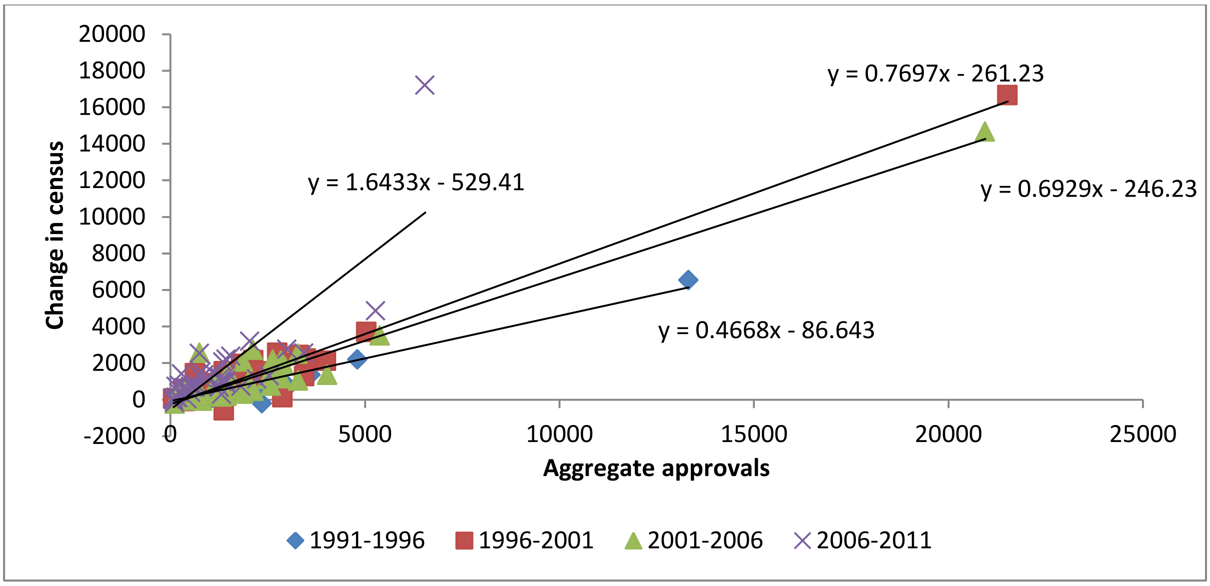


Figure A2: Approvals and Outcomes for Apartments



The x-axis in Figure A1 measures the actual change in the number of houses between censuses in a LGA, while the y-axis measures the sum of building approvals for houses in an LGA over an equivalent period. Figure A2 reports the same data for apartments. If approvals and outcomes were perfectly linked (over the five year intervals) then all points should lie on the 45 degree line. For houses we see that the approvals data tend to overestimate the actual increase in housing stock as measured by the census. In contrast for the apartments data approvals tend to underestimate the actual increase.

Despite the apparent limitations with the approvals data, in the absence of anything better, we use the annual approvals data to interpolate the Census figures. To illustrate our methodology the following table, Table A1, shows the calculation of the annual stock of houses in the Baulkham Hills LGA.

Table A1: Interpolated Stock of Houses for Baulkham Hills

Year	Census	Change	Approvals	Sum	Error App	Adj Stock	Annual
1990-91	**34,028**	**na**	**na**	**na**			**34,028**
1991-92			559			76.4	34,663
1992-93			512			76.4	35,252
1993-94			597			76.4	35,925
1994-95			681			76.4	36,683
1995-96	**37,292**	**3,264**	**533**	**2,882**	**382**	**76.4**	**37,292**
1996-97			909			-89.6	38,111
1997-98			1,641			-98.6	39,663
1998-99			1,775			-98.6	41,348
1999-00			1,932			-98.6	43,191
2000-01	**44,541**	**7,249**	**1,440**	**7,697**	**-448**	**-98.6**	**44,541**
2001-02			2,127			275	46,943
2002-03			1,481			275	48,699
2003-04			948			275	49,922
2004-05			632			275	50,829
2005-06	**51,556**	**7,015**	**452**	**5,640**	**1375**	**275**	**51,556**
2006-07			465			201.4	52,222
2007-08			411			201.4	52,835
2008-09			298			201.4	53,334
2009-10			350			201.4	53,886
2010-11	**54,574**	**3,018**	**487**	**2,011**	**1007**	**201.4**	**54,574**
2011-12			363				54,937

Notes: Inter-census stocks of houses are calculated by taking the previous census figure and adding approvals plus an adjustment equal to one-fifth of the difference between the change in the house stock between censuses and the comparable sum of approvals. For example the figure for 1996-97 is 38,111 = 37,292 + 909 + (7,249 – 7,697)/5.

Population

The following sources provide data for Estimated Resident Population for LGAs on end of financial year basis (end-June) for the period 1995-96 to 2011-12. Source: Regional Population Growth, Australia, 1996-2006, 2008-09, 2011 (cat. no. 3218.0).

For data for the period 1990-91 to 1994-95 we use data from tables produced by the UNSW Local Grants Commission. This reports (preliminary) population estimates over the period 1990-91 to 2010-11. No data are reported for 1991-92, so we simply use the average of 1990-91 and 1992-93 for this year. Source: ABS Estimated Resident Population of Statistical Local Areas New South Wales at 30 June 1990 Preliminary (Cat. No. 3210.1)

Income

Estimates of income for LGAs are based on data from the Australian Taxation Office's *Taxation Statistics.* The Bureau of Infrastructure, Transport and Regional Economics (BITRE) has a database derived from the ATO data that report by LGA real income per taxpayer (in 2007-08 prices) for the period 1990-91 to 2005-06. The original figures for nominal taxable income are deflated using the CPI for Australia.

For the period 2006-07 to 2009-10 the ABS reports data by LGA for nominal income per taxpayer in their *National Regional Profile 2007-2011.* We convert these figures to constant 2007-08 prices using the CPI for Australia.

As we have no income data by LGA for the financial years 2010-11 and 2011-12, we simply assume that the growth rate of real income per taxpayer in both 2010-11 and 2011-12 is equal to the growth rate for 2009-10.

Real Interest Rate

Data on the real interest rate is obtained from the RBA spreadsheet *Capital Market Yields* (F2). It is the yield on the Australian Government inflation-indexed bond with the longest maturity.

Consumer Price Index

The consumer price index for Sydney is obtained from ABS release 6401.0 - *Consumer Price Index, Australia.*

Development Approvals

Median and mean times required by Local Councils to decide on a DA are reported in *Comparative Information on NSW Local Government,* and are available from 1994-95 to 2011-12.

Geographic Variables

The geographic variables are obtained from three satellite-based geographic databases:

(i) GEODATA TOPO 250K Series 3

(ii) SRTM Digital Elevation Data, Australia; and

(iii) Local Government Area Digital Boundaries (ASGC 2006) in ESRI Shapefile format)

using GDAL and GIS software. The first dataset, sourced from Geoscience Australia, provides a vector representation of the major topographic features appearing on the 1:250,000 scale NATMAPs. This allows us to calculate the area of each LGA that is taken-up with hydrology (e.g. lakes, reservoirs, watercourses and flats); habitation (e.g. build-up and recreation areas) and prohibited areas and reserves. The second dataset (DEM) is a digital SRTM map with a resolution of 90 metres at the equator, sourced from CGIAR-CSI. The third dataset, sourced from the Australian Bureau of Statistics, is LGA digital boundaries across Australia, which guarantee the LGA-specific level of the variables derived.

Geo1

This variable measures amount of land in an LGA that is unavailable for housing development due to natural geographic features, Saiz (2010). It equals the land area in an LGA that has:

- a slope that is at least 50% or
- is covered by a lake, reservoir, watercourse, or flat (flats include land that is subject to inundation, marine swamp, saline coastal swamp or swamps).

Geo2

This variable adds to *Geo1* the amount of land in an LGA that is taken-up by: airports, cemeteries, reserves, recreation areas and prohibited areas. Reserves include forestry, indigenous, conservation and water supply reserves. A prohibited area means that entry is prohibited without permission from the controlling authority. Recreation areas include: civic squares, gardens, golf courses, land used for multiple recreation purposes, ovals, racecourses, rifle-ranges and show-grounds.

Geo3

This variable measures the amount of land in an LGA that can be classified as built-up area. The Australian Road Rules define built-up area as an area in which there are buildings on land next to the road, or there is street lighting, at intervals not over 100 metres for a distance of at least 500 metres or, if the road is shorter than 500 metres, for the whole road.
http://www.ntc.gov.au/viewpage.aspx?documentid=00794