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Residential construction and population growth in New Zealand: 1996-2016

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Abstract

Between 1996 and 2016 Auckland's population increased by 499,000, or by slightly more than the increase in the rest of New Zealand. Yet only half the number of building permits were issued in Auckland as in the rest of the country. To understand this difference, this paper uses regional data to investigate how population growth affects residential construction. It estimates that if Auckland had built houses at the same rate as the rest of the country (adjusted for population growth) it would have needed to have built an additional 40 – 55,000 dwellings during the period – and needed nearly 9000 more construction sector workers. The shortfall was modest until 2005, but sharply accelerated due to the cessation of apartment building in central Auckland. The results show the large increase in the average size of dwellings was not a major factor in Auckland's shortfall relative to the rest of the country as new dwellings were smaller in Auckland than elsewhere.

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[1] The views expressed in this paper are those of the author(s) and do not necessarily reflect the views of the Reserve Bank of New Zealand, and the Productivity Commission. Andrew Coleman: Productivity Commission and Otago University, and Özer Karagedikli: Reserve Bank of New Zealand. We thank, without implication, Paul Conway, Roderick Deane, Gary Hawke, Enrique Martinez-Garcia, Anella Munro, Chris Parker, Peter Redward, Tom Smith and the seminar participants at the Reserve Bank of New Zealand, Productivity Commission, University of Otago and Auckland Council for valuable comments. Reserve Bank of New Zealand, 2 The Terrace, Wellington 6011, Po Box 2498, Wellington 6140, New Zealand. Phone (64) 4 471 3827; Fax (64) 4 472 2029; Email ozer.karagedikli@rbnz.govt.nz.
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The estimates further suggest population change may be ‘hyper-expansionary’ as the residential construction demand associated with an additional person is higher than the output they produce. In these circumstances, population increases raise the demand for labour and create pressure for additional inward migration, potentially explaining why migration-fueled boom-bust cycles may occur.

Non-technical summary

This paper aims to understand how population growth has affected building activity in New Zealand regions during the last twenty years. Using panel data regression techniques, we estimate that 0.25 – 0.30 additional houses are built for every additional person in a region. The additional 0.25 – 0.30 building permits per person equate to about 40 m^2 of new construction, with a value of just over $60,000 in 2016 terms. This construction is in addition to the 'background' construction that occurs to replace old houses, which amounts to 2.5 – 3.0 dwellings per 1,000 people per year, or approximately 11,000 – 13,000 dwellings per year.

The estimates suggest Auckland's construction shortfall between 1996 and 2016 was between 40,000 and 55,000 dwellings, or approximately 10 percent of Auckland's housing stock. The estimates of the shortfall are fairly robust to changes in the specification of the models; moreover, they all suggest that the shortfall was modest until the end of 2005, after which it increased rapidly.

We also examine the relationship between the size of newly constructed dwellings and population change. Since four of the sixteen New Zealand regions experienced almost no population growth over the period, it is possible to contrast the size of newly constructed houses in regions experiencing population change with those that did not. These estimates suggest that, at least until 2005, smaller houses were constructed in growing regions with above-average incomes, particularly Auckland and Wellington, than in growing regions with below average incomes or in regions with no population growth. This difference appears to reflect the much younger age profile of the residents of Auckland and Wellington. It appears that Auckland's housing shortfall was less severe prior to 2005 precisely because of the large number of small apartments that were constructed in the city. Not until apartment construction almost completely ceased in 2008 did Auckland's housing shortage started to become acute.

Finally, we analyse the relationship between population growth rates and the number of 'residential' construction workers. Our estimates suggest that a 1 percent increase in population growth rates is associated with a 0.4 – 0.5 percentage point increase in the fraction of the workforce in the construction sector. Since regions with zero population growth have 4.5 – 5 percent of their workers involved in residential construction, each percentage increase in the population growth rate increases the number of residential construction workers by approximately 10 percent. This does not include additional workers in related industries such as building materials. Auckland is again an

outlier. For most of the period Auckland had approximately 9000 fewer construction workers than could be expected from trends around the rest of the country. Clearly, if this shortfall continues it will be difficult for Auckland to overcome its housing shortage.

1 Introduction

Rapid population growth has been one of the most striking features of New Zealand's economy in recent years. The migration-fueled population increase, in excess of 1 percent per year, created buoyant conditions for New Zealand's construction and real estate markets. Real estate prices increased by more than 200 percent in real terms between 1992 and 2016, and the fraction of New Zealand's workforce in the construction sector increased from 4.8 percent in 1992, a post-1970 low, to 7.7 percent in 2009 (prior to the Christchurch earthquake) and 8.2 percent in 2016. However, the population increase was not the only factor behind the active residential construction sector. Between 1991 and 2016 the average size of newly constructed houses increased from 132m^2 to 191m^2, a faster rate of increase than in either Australia or the United States, the only two countries for which comparable data are available.[2] Builders were busy not only because more houses were needed for a larger population, but because people also wanted larger houses.

Auckland's population increase was particularly large. The number of residents increased by 45 percent between 1996 and 2016, or by more than twice as much as the 18 percent increase recorded in the rest of the country (see Table 1). Despite an increase in building activity, several indicators suggest insufficient houses were built in Auckland to keep up with the population increase. Even though the population increased more in Auckland than the rest of New Zealand put together, only half as many new dwellings permits were issued in Auckland as the rest of the country, 153,000 versus 304,000. Moreover, prices increased much faster in Auckland than the rest of the country, by 406 percent in real terms. Finally, the size of Auckland's construction sector is smaller as a fraction of the workforce than the rest of the country.

To better understand how the construction sector responds to demand pressures, this paper estimates how population growth has affected building activity in New Zealand during the last twenty years. Figure 1, which plots the relationship between population growth rates and new residential building permits per person across sixteen regions, shows the basic idea. Fifteen of the points lie close to a line with a slope approximately equal to one third, or one

[2] New Zealand data are for 1990 and 2014; the increase is 43%. US data are available for the same period and show a 31% increase. Australian data are only available up to 2010. See footnote 13 for sources.

new dwelling for every three extra people. The last point, representing Auckland, lies far below this line. A simple extrapolation suggests that if Auckland had built at the same rate as the rest of the country, an additional 50,000 to 60,000 houses would have been built.

The first purpose of this paper is to refine this estimate using more complex statistical techniques to account for a number of econometric issues that necessitate the use of higher data frequency. Population estimates for the sixteen regions are available on an annual basis from 1996 onwards, but regressions using annual data are not particularly useful because of delays between when population changes and building activity occur. These delays can be exacerbated by capacity constraints in the construction industry, for when these bind a large population increase can cause a backlog of construction activity that takes several years to clear. These constraints suggest the relationship between population change and construction activity can be highly variable over short periods of time, even if it is stable over longer periods. These delays can also be expected to induce complex patterns of serial correlation into the data.

Using panel data regression techniques, we estimate that 0.25 – 0.30 additional houses are built for every additional person in a region. We control for different combinations of regional and time fixed effects to allow for different regional patterns and for different shocks such as the global financial crisis, with different lag structures, and with different ways of estimating standard errors to explore the robustness of the results.

The additional 0.25 – 0.30 building permits per person equate to about 40 m^2 of new construction, with a value of just over $60,000 in 2016 terms. This construction is in addition to the 'background' construction that occurs to replace old houses, which amounts to 2.5 – 3.0 dwellings per 1,000 people per year, or approximately 11,000 – 13,000 dwellings per year. The additional construction associated with a new person is more than New Zealand's per capita Gross Domestic Product, which in 2016 was $54,178.[3] This suggests that net inward migration is likely to be hyper-expansionary, as the immediate demand for housing by immigrants exceeds their productive potential. The estimates also suggest Auckland's construction shortfall between 1996 and 2016 was between 40,000 and 55,0000 dwellings, or approximately 10 percent

[3] Statistics New Zealand. Regional Gross Domestic Product: Year ended March 2016, published March 30, 2017.

of Auckland's housing stock. The estimates of the shortfall are fairly robust to changes in the specification of the models; moreover, they all suggest that the shortfall was modest until the end of 2005, when it increased rapidly.

The second purpose of the paper is to examine the relationship between the size of newly constructed dwellings and population change. Since four of the regions experienced almost no population growth over the period, it is possible to contrast the size of newly constructed houses in regions experiencing population change with those that did not. These estimates suggest that, at least until 2005, smaller houses were constructed in growing regions with above-average incomes, particularly Auckland and Wellington, than in growing regions with below average incomes or in regions with no population growth. This difference appears to reflect the much younger age profile of the residents of Auckland and Wellington. It appears that Auckland's housing shortfall was less severe prior to 2005 precisely because of the large number of small apartments that were constructed in the city. Not until apartment construction almost completely ceased in 2008 did Auckland's housing shortage start to become acute.

The third aim of the paper is to analyse the relationship between population growth rates and the number of 'residential' construction workers. Our estimates suggest that a 1 percent increase in population growth rates is associated with a 0.4 – 0.5 percentage point increase in the fraction of the workforce in the construction sector. Since regions with zero population growth have 4.5 – 5 percent of their workers involved in residential construction, each percentage increase in the population growth rate increases the number of residential construction workers by approximately 10 percent. This does not include additional workers in related industries such as building materials. Auckland is again an outlier. For most of the period Auckland had approximately 9000 fewer construction workers than could be expected from trends around the rest of the country. Clearly, if this shortfall continues it will be difficult for Auckland to overcome its housing shortage.

2 A Simple Model of Population Growth, Housing Stock and Building Activity

This section develops a simple model to explore how building activity is affected by population growth and depreciation.

Let H_t = stock of houses at the beginning of period t

P_t = population at the beginning of period t

BP_t	=	building permits issued between *t* and *t+1*
BP_t^*	=	building put in place at time between *t* and *t+1*
H_t	=	the number of houses that depreciate between *t* and t+1
α	=	demand for housing per person, approximately one third.

The empirical analysis conducted in this paper is based on building permit data, not the actual amount of construction taking place. In practice the difference between these two series is small for, as Statistics New Zealand (2017) observes, approximately 95 percent of building permits result in construction, and most of this construction takes place within a year of the issue of the permit.[4] Nonetheless, the following derivation makes allowance for this potential difference by assuming the actual amount of building activity may differ from the amount of building permits by a random amount:

$$BP_t^* = wBP_t + e_t \qquad (1)$$

The coefficient *w* is the average fraction of building permits that are subsequently constructed.

The stock of housing, which is not observed by the econometrician, is

$$H_t = (1-\delta)H_{t-1} + BP_{t-1}^* \qquad (2)$$

Population change is a random variable:

$$n_t = \Delta P_{t+1} = P_{t+1} - P_t \qquad (3)$$

Let U_t be a measure of unmet housing demand at the beginning of the period. We assume that the demand for housing per person depends only on the

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[4] Between March 1998 and March 2017 147,149 permits were issued in Auckland and 295,939 in the rest of the country. The number of completions were 138,229 (93.9 percent) and 280,249 (94.4 percent) respectively. Source: Subnational dwelling permits and completion estimates by Statistics NZ, July 2017.

population:

$$U_t = \alpha P_t - H_t \tag{4}$$

Suppose α is independent of prices. New housing demand z_t during a period is a function of the population change n_t and the depreciation of the housing stock that occurs in the period:

$$z_t = \alpha n_t + \delta H_t \tag{5}$$

Potential demand during period t is therefore

$$\begin{aligned} U_t^* &= U_t + z_t \\ &= U_t + (\alpha n_t + \delta H_t) \end{aligned} \tag{6}$$

Note that

$$\begin{aligned} U_t &= \alpha P_t - H_t \\ &= \alpha(P_{t-1} + n_{t-1}) - ((1-\delta)H_{t-1} + BP_{t-1}^*) \\ &= U_{t-1} + z_{t-1} - BP_{t-1}^* \\ &= U_{t-1}^* - BP_{t-1}^* \end{aligned} \tag{7}$$

Assume the number of building permits is a linear function of potential demand plus a random disturbance term:

$$BP_t = \lambda^0 U_t^* + v_t^0 \tag{8}$$

Then

$$\begin{aligned} BP_t^* &= w(\lambda^0 U_t^* + v_t^0) + e_t \\ &= \lambda U_t^* + v_t \end{aligned} \tag{9}$$

and

$$\begin{aligned} BP_t^* &= \lambda(U_t + z_t) + v_t \\ &= \lambda(U_{t-1}^* - BP_t^* + z_t) + v_t \\ &= \lambda\left(U_{t-1}^* - \lambda U_{t-1}^* - v_{t-1} + z_t\right) + v_t \\ &= \lambda z_t + \lambda(1-\lambda)U_{t-1}^* + (v_t - \lambda v_{t-1}) \\ &= (\lambda\alpha n_t + \lambda\delta H_t) + \lambda(1-\lambda)U_{t-1}^* + (v_t - \lambda v_{t-1}) \end{aligned} \tag{10}$$

When $0 < \lambda < 2$, the level of potential demand will be a stationary variable if the population demand shocks n_t and the shocks to building supply v_t are stationary, even if building activity does not respond fully and instantaneously to demand shocks:

$$\begin{aligned} U_t^* &= z_t + U_t \\ &= z_t + \left[\alpha(P_{t-1} + n_{t-1}) - ((1-\delta)H_{t-1} + BP_{t-1}^*)\right] \\ &= z_t + (\alpha P_{t-1} - H_{t-1}) + (\alpha n_{t-1} + \delta H_{t-1}) - (\lambda U_{t-1}^* + v_{t-1}) \\ &= z_t + U_{t-1}^* - \lambda U_{t-1}^* - v_{t-1} \\ &= z_t + (1-\lambda)U_{t-1}^* - v_{t-1} \end{aligned} \tag{11}$$

If the building industry responds immediately and fully to demand, $\lambda = 1$ and the equation simplifies to[5]

$$BP_t^* = \alpha n_t + \delta H_t + v_t \tag{12}$$

In this case, a regression of building permits against the population growth rate should recover an unbiased estimate of α, and the residuals of the equation should be uncorrelated through time if the idiosyncratic shocks v_t are uncorrelated.

If $\lambda \neq 1$, the expected value of the population growth regression coefficient will be $\lambda\alpha$, not α, and the error term will have two serially correlated components. The first component occurs because the unobserved variable U^*_{t-1} is not included in the regression. It will have positive serial correlation if population shocks have positive serial correlation or if $\lambda < 1$ and unmet demand is carried over from period to period (equation 11). The second component reflects the negative moving average component associated with the building supply shocks v_t. It is negatively correlated because shocks occurring one period are made up in subsequent periods. The overall serial correlation of the error process could be positive or negative depending on the relative size of the shocks.

As the amount of unmet demand is not observed, the relationship between

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[5] If the building industry responds fully to potential demand, $\lambda=1$ but $\lambda_0=1/w >1$ to allow for the fraction of issued permits that are not built.

building activity and population change cannot be estimated in an entirely satisfactory manner. One approach is to regress building permits against contemporaneous population growth, with lagged population growth included as a proxy for unobserved unmet demand. The total effect of population growth on building activity is found by summing the coefficients on different lags. This sum will be biased downwards if insufficient lags are used. An alternative approach is to aggregate the data into fewer but longer periods, say two-year periods or four-year periods instead of one-year periods. We do both, although prefer aggregating the data into longer length horizons. As the observation period is lengthened, more of the building sector's response to demand shocks occurs within the contemporaneous period and the coefficient between building permits and population change will be closer to the true long run occupancy ratio α. Nonetheless, the coefficient will still be downwardly biased as some of the building associated with the population increase taking place at the end of the period will take place in the subsequent period.

The bias can be calculated for different values of the parameter λ. Consider aggregating two periods, t and t+1, together. It follows from equations 10 and 11 (recalling that $z_t = \alpha n_t + \delta H_t$)

$$BP_t^* = \lambda z_t + \lambda(1-\lambda)U_{t-1}^* + (v_t - \lambda v_{t-1})$$

$$\begin{aligned} BP_{t+1}^* &= \lambda z_{t+1} + \lambda(1-\lambda)U_t^* + (v_{t+1} - \lambda v_t) \\ &= \lambda z_{t+1} + \lambda(1-\lambda)\left(z_t + (1-\lambda)U_{t-1}^* - v_{t-1}\right) + (v_{t+1} - \lambda v_t) \\ &= \lambda z_{t+1} + \lambda(1-\lambda)z_t + \lambda(1-\lambda)^2 U_{t-1}^* + \left(v_{t+1} - \lambda v_t - \lambda(1-\lambda)v_{t-1}\right) \end{aligned} \tag{13}$$

Adding the two periods together,

$$\begin{aligned} BP_t^* + BP_{t+1}^* = &\left[\lambda z_{t+1} + \lambda\left(1 + (1-\lambda)\right)z_t\right] \\ &+ \left[\lambda(1-\lambda)(2-\lambda)U_{t-1}^*\right] \\ &+ \left[v_{t+1} + (1-\lambda)v_t - \lambda(2-\lambda)v_{t-1}\right] \end{aligned} \tag{14}$$

If a third period were added

$$
\begin{aligned}
&BP_t^* + BP_{t+1}^* + BP_{t+2}^* \\
&\qquad = \left[\lambda z_{t+2} + \lambda\left(1+(1-\lambda)\right)z_{t+1} + \lambda\left(1+(1-\lambda)+(1-\lambda)^2\right)z_t\right] + \\
&\qquad + \left[\lambda(1-\lambda)\left((1+(1-\lambda)+(1-\lambda)^2\right)U_{t-1}^*\right] \\
&\qquad + \left[v_{t+2} + (1-\lambda)v_{t+1} + (1-\lambda)^2 v_t - \lambda\left((1+(1-\lambda)+(1-\lambda)^2\right)v_{t-1}\right]
\end{aligned} \tag{15}
$$

The formula can be readily extended to longer periods.

Equation 15 can be interpreted as follows. When three years are combined into a single period, the fraction of the desired building activity taking place within the three years depends on the years in which the population increase occurs. If the population increase takes place in the third year, only a fraction λ of the new houses will be built by the end of the combined period. If the population increase takes place in the second year, a fraction λ(1+(1-λ)) of the new houses will be built by the end of the combined period. If the population increase takes place in the first year, a fraction $\lambda(1+(1-\lambda)+(1-\lambda)^2)$ of the new houses will be built by the end of the combined period. The average response can be calculated as an average of the different response over the three years. As the length of the combined period increases, it can be shown that almost all new houses will be built in the same period as the population increase.[6] For this reason, the estimated coefficient between the number of building permits and the population change should increase as the length of the combined period increases, and approach the true parameter α asymptotically.

The ratios of the coefficients estimated using different period lengths depend on the parameter λ. In section 4 of the paper we aggregate data into periods that vary between one year and twenty years and show the estimated

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[6] If N periods are joined together, the quantity of building activity associated with a set of population shocks z occurring from sub-periods 0 to N-1 will be

$$S_N(z) = \lambda\left[z_{t+N-1} + (1+(1-\lambda))z_{t+N-2} + \ldots + (1+(1-\lambda)+\ldots(1-\lambda)^{N-1})z_t\right]$$

It is straightforward to show $\lim_{N\to\infty} \frac{\lambda S_N(1)}{N} = 1$. It follows that if *z* is a stationary sequence, the average fraction of building activity associated with a change in population that occurs within a period approaches 1.

coefficients increase as the period length increases and appear to converge. By comparing the coefficients estimated using different length periods with the theoretical relationship implied by equation 15 (or its equivalent for longer periods), it is possible to get a sense of the size of the parameter λ. The estimated numbers suggest that λ lies between 0.6 and 0.8, which means 60 – 80 percent of the housing demand induced by population change is started within a year. If $\lambda = 0.6$, and we examine 4-year periods, 84 percent of new houses should be built in the same period that the population change occurs, with the rest occurring afterwards. If $\lambda = 0.7$, the figure rises to 89 percent. These numbers suggest that when we aggregate the data into 4-year periods we are likely to underestimate the number of building permits associated with population change, by 10 – 17%. In turn, this means we are likely to underestimate Auckland's building shortfall.

Why might we prefer to choose longer periods rather than estimate a regression using one-year periods and several lags? One reason is practical: it is difficult to estimate the coefficients of a large number of lagged variables accurately if they are serially correlated, even with a lot of data. A second issue concerns the effects of capacity constraints on building activity. Whenever an industry has capacity constraints that occasionally bind, the timing of the supply response to different sized demand shocks will vary. It may take three years to respond to an unusually large population influx, for instance, whereas the demand from a small population increase might be met within the year. If this is the case, the lag structure between population changes and building permits will not be constant. Moreover, regression estimates will be biased as the residuals of the estimated equations will be correlated with the lags of the population variable. These problems are reduced by increasing the size of the period, for then most of the building activity associated with different sized shocks takes place within the period.

3 Data Sources

Statistics New Zealand collects data on the size, type, number and dollar value of building permits. Some of these data are freely available from Statistics New Zealand's Infoshare database, while others have to be purchased separately. The basic regressions in section 4 and 5 are estimated using annual Infoshare data for the period July 1996 – June 2016 (Data series: Infoshare BLD113AA). These data include the number, area and nominal value of building permits issued for new units, and the number and value of building permits issued for alterations. The data cover sixteen different regions. Data from 1991 to 1996 were obtained from the same source, but are not used in most of the analysis as they could not be matched to population data.

Annual regional population figures are available from Statistics New Zealand from 1996 (Data series: Infoshare DPE051AA.) We use estimates for the population at the end of June for each year. In addition, we use population figures from the 1991 census to calculate five-year population growth rates from 1991 to 1996.

The most detailed sources of regional age-specific demographic information are the Statistics New Zealand censuses, which are available for 1996, 2001, 2006 and 2013. Although these data provide estimates of the population broken down into five-year age groups, the irregular frequency of the censuses limit their usefulness. Nonetheless, we combine the census data with the annual estimates of the population of four age groups (0 – 14; 15 – 39; 40 – 64; and 65 plus) that Statistics New Zealand produced for the period 2007 – 2016 to create age-specific demographic variables. (Data series: Statistics New Zealand, Subnational population estimates (RC, AU), by age and sex, at 30 June 1996, 2001, 2006-17 (2017 boundaries).)

Statistics New Zealand provided us with a special compilation of data that gives the number of dwellings disaggregated by type (stand-alone houses, apartments, townhouses, independent living units in retirement villages) in eight size categories (< 100 m2; 100-150 m2; 150-200 m2; 200-250 m2; 250-300 m2; 300-350 m2; 350-400 m2 > 400 m2). The data were compiled for 16 New Zealand regions and 12 wards of the Auckland region, and are available on an annual basis from 1991 – 2014. The data also include the value of permits, and the total area of permits.

We deflate the nominal value of building permits by the residential building component of the Capital Goods Price Index (Data series: CEP007AA). We do not have separate indices for different regions. Between June 1996 and June 2016 this index increased by 95 percent. The nominal value of alterations was also deflated by this series.

In section 6 we examine trends in regional construction sector employment. We exclude workers engaged in heavy engineering construction projects such as roads or commercial buildings by only including the number of firms and employees in the construction sectors E30 and E32.[7] (Data series: Statistics New Zealand Business Demographic Statistics "Geographic units by region and industry 2000-2016".)

4 Estimating the Effect of Population Growth on Building Permit Numbers

In this section we analyse the relationship between population growth rates and the number of building permits. We first estimate equations that vary in terms of the length of a period, but which do not include lagged population growth rates. In section 4.2 we estimate models that include lags, and in section 4.3 we estimate models that incorporate additional demographic information.

4.1 Models excluding lagged population growth

We estimate the following equation:

$$\begin{aligned} BP_{it}^{h} &= \alpha_0^h + \alpha_1^h region\ dummy_i + \alpha_2^h time\ dummy_t + \alpha_3^h Christchurch \\ &\quad + \alpha_4^h \Delta Popn_{it} + e_{it}^h \end{aligned} \tag{16}$$

where BP_{it}^{h} is the number of building permits per capita in region *i* during period *t*, and *h* refers to the length of the period in years;

Christchurch is a dummy variable equal to 1 for time periods after the 2010 earthquake, and zero otherwise; and

$\Delta Popn_{it}$ is the population change in region *i* during period *t*, as a fraction of the initial population.

In each case the regression included a full set of regional and time dummy variables.[8] The regressions are estimated separately either using the 15 regions

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[7] Data are only available for 15 regions as Tasman and Nelson are combined.

[8] The equations were also estimated without regional dummy variables, in which case the standard errors were calculated using Thompson clustered standard errors. As the regional dummy variables were typically statistically significant, we kept them in our preferred

excluding Auckland or the 16 regions including Auckland. The data are aggregated into different length periods, where the length of the periods, *h*, is equal to either 1, 2, 4, 5, 10 or 20 years. We test the residuals for first order serial correlation for period lengths less than or equal to five years.[9] We do not estimate the serial correlation structure if the period length is ten or twenty years as there are insufficient observations.

Table 2 contains the level and standard errors of the estimated coefficients $\hat{\alpha}_4$, the R^2 of the regression, and the estimated serial correlation of the errors for regressions estimated using different period lengths. The coefficients are estimated using ordinary least squares and the standard errors are calculated using the Huber -White method.

The top panel in table 2 reports the results when Auckland is excluded from the regressions. The main coefficient of interest, α_4, on the variable $\Delta Popn_{it}$ is smallest for the short length periods *(h = 1, 2)*, and gets larger as the length of the period increases. When the period length is short, the estimated errors have statistically significant positive correlation. We suspect this is due to capacity constraints in the building sector: in the short-term a large increase in population will generate large amounts of construction in successive periods as not all of the demand will be met immediately. The positive serial correlation in the error structure will be exacerbated if population growth rates have positive serial correlation. At longer horizons, however, there may be negative serial correlation in the error structure, as builders compensate for under or over supply in earlier periods. For example, if construction activity is less than required during a five-year period it may be made up in the subsequent five years, generating a negative serial correlation pattern in the residuals.

The residuals of our estimated regressions have these patterns. The residuals of the one or two-year period regressions have large and statistically significant positive serial correlation, consistent with the existence of capacity constraints. However, the residuals of the five-year period regressions are negatively correlated, and significant at the 10 percent confidence level. The

specification.

[9] If the estimated errors are serially correlated, we also estimated the equation using feasible general least squares estimation. The results are similar and are available from the authors upon request.

residuals of the four-year period regressions only have small and statistically insignificant serial correlation, possibly because the two forces offset each other.

The bottom panel in table 2 reports the results when Auckland data are included in the regressions. The two sets of results are almost identical except for the twenty-year period regressions, when there is only a single observation for each region and fixed regional effects cannot be included. In the shorter period regressions, the inclusion of regional and time dummy variables mean the coefficient on the population growth variable is estimated from within-region variation in population growth rates and building permit numbers, not across regional variation, and the inclusion or omission of Auckland makes little difference to the results. Including Auckland in the twenty-year period regression reduces the estimated coefficient $\hat{\alpha}_4$, as building activity in Auckland is much lower than can be expected from the pattern in other regions (see Figure 1). We again focus on the four-year period regressions as the residuals appear serially uncorrelated.

The estimated coefficients $\hat{\alpha}_4$ in the 4-year horizon regressions are 0.235 and 0.247 respectively when Auckland is excluded or included, implying that 0.235 - 0.247 new housing permits are issued for each additional person. The coefficients are precisely estimated with standard errors of 0.027 and 0.025 respectively, and the overall fit in these regressions are 0.88 and 0.89. Even if these coefficients underestimate the long run effect of population growth on building activity by a sixth, because some construction occurs after the period ends, less than 0.3 houses are built for each new person. This suggests that the marginal effect of population change on building activity is less than the average housing/population ratio. This population related-construction is over and above construction that replaces old or depreciated houses, which is captured by the constants. The constants vary across regions but the average value is between 2.5 and 3.0 building permits per 1000 population.

We use the estimated coefficients from the table 2 to calculate the accumulated housing shortage in Auckland based on the relationship between building activity and population increases in the rest of the country. The last column in table 2 shows the estimated accumulated shortage as of 2016. With one exception, the models suggest Auckland's housing shortage is between 38,000 and 59,000 houses.[10] The estimated shortage in 2016 of our preferred four-

[10] The estimated shortfall using the regression that uses twenty-year period data excluding

year horizon model is 54,000.

Figure 2 shows the estimated accumulated shortage in Auckland for the 1997-2016 period made using the 4-year horizon regression coefficients. The shortage was modest until 2003. Between 2004 and 2005 the housing shortage reduced, reflecting a substantial increase in apartment building (this is discussed in more detail in section 5). However, the shortage is estimated to have increased sharply after 2006.

The Auckland housing shortage we estimate is larger than the estimate of 20,000 to 30,000 cited in Spencer (2016). Part of the difference reflects a difference in methodology: the estimate in this paper calculates the shortfall under the assumption that population changes in Auckland have the same effect on the demand for housing as they do in the rest of the country. This would not be the case if people in Auckland wanted higher occupant/housing ratios than people in the rest of the country, possibly because Auckland has a younger population or because house prices are higher. Moreover, demolition rates could be lower in Auckland than elsewhere because the average age of the housing stock is lower, which would produce lower estimates of the shortfall.[11] The accumulated shortfall is also calculated relative to 1996, an earlier (and more explicit) year than some other estimates. Nonetheless, the estimates made in this paper have a lower marginal occupant/dwelling ratio than those often used to estimate Auckland's housing shortage, as the estimates are based on the marginal rather than average occupant/housing ratios prevailing in other regions of the country.

4.2 Models including lagged population growth

For robustness purposes, we estimate the equation with one, two or three lags of population growth in addition to the contemporaneous period population growth. The coefficients on even longer lags were small and never significantly different from zero. These results are reported in table 3. The

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Auckland is 84,500. This regression only has 15 observations, and the coefficient is estimated using cross-region not within-region variation.

[11] Auckland's housing stock is younger on average than the rest of the country because the city has grown rapidly, which might suggest demolition rates are lower (and that we over-estimate the shortage because fewer houses are knocked down than in the rest of the country.) However, the pressure for intensification is higher in Auckland than elsewhere, which might result in more demolitions as developers seek to build multiple units on valuable sections.

lagged models are estimated using annual data as well as data aggregated into two or four-year periods. As the coefficients on the lagged population growth variables in the models using one and two-year period data are positive and statistically significant, the total amount of building activity associated with population growth is larger than estimated in the one and two-year horizon period length models in table 2. Nonetheless, the estimates suggest most building activity associated with population increases takes place within four years, with the vast majority of that taking place within two years. In other respects, the regressions have very similar features to the results in table 2. The coefficients indicate the effect of contemporaneous population increases on building activity still increase as the period length increases. The first order serial correlation pattern is almost identical. The regression using shorter–length data have positively correlated residuals but there is no serial correlation in the residuals estimated using four-year period data.

In the equation with four-year periods, the coefficient on lagged population growth is 0.038, but it is not statistically significant from zero at 5 percent significant levels. The coefficient on contemporaneous population growth is 0.256. The sum of the coefficients is 0.294, of which 87 percent takes place in the contemporaneous period. This suggests our preferred specification in section 4.1, which excludes lags, is not badly mis-specified. It may be recalled from the theoretical model in section 2 that if 70 percent of housing demand is constructed within a year, 87 percent of the housing associated with population increases that occur within a four year period will be constructed within the four years. It thus appears the data are broadly consistent with the model in section 2 with a parameter λ equal to 0.7.

The estimated Auckland housing shortage is larger at every horizon relative to the estimates in table 2. When a lag is included in the four-year period regressions, the estimated Auckland shortfall in 2016 increases from 54,000 dwellings to 65,500.

Grimes and Hyland (2015) estimated a model of housing supply and demand using quarterly data from 72 territorial local authorities over the period 1996 – 2012. Using a panel cointegration response based around long run supply and demand equations, they estimated a short-run lagged response function based on the indirect response from population to prices and from prices to building activity. They used the results from this model to estimate how long it would take for building activity to respond to an increase in population that took place over a five-year period. They estimated that only half of the building activity would occur within six years of the start of the population increase, and that the whole adjustment would take nine years. Our estimates suggest that building activity responds to demand much more quickly than this. Consider the response to 100 people moving into a region over a four-year period. Using the four-year period regression, we estimate 26 building permits would be issued within the initial four years, and a further 4 permits would be issued in the subsequent four-year period, although the latter number is not estimated accurately and it is not statistically different from zero. This means over 85 percent of the building permits are issued within the initial four-year period. [12] We suspect the estimates of Grimes and Hyland substantially over-estimate how long it takes for the building sector to respond to population changes, at least in areas of New Zealand outside Auckland.

4.3 Models including age-specific population information

The above models assume that the number of new dwellings does not depend on the age structure of the population. This assumption could be important, as Auckland's population age structure is quite different to that of most other regions of the country. Moreover, there is international cross-country evidence suggesting that, *at the national level*, the amount of residential construction depends on the age structure of the population, not just the total number of people (Lindh and Malmberg 2008; Monnet and Wolf 2017). Monnet and Wolf, for example, argue that the key determinant of residential construction in 20 OECD countries (excluding New Zealand) is the growth in the population of people aged 20 – 49.

Unfortunately, there are significant data limitations that restrict us from comprehensively estimating how the number of the new dwellings in a region depends on the age-structure of the population. For example, we do not have regional data on the number of people aged 20 – 49. Nonetheless, in the appendix we provide results that suggest that the age-structure of the new residents in a region did not have a major effect on the total demand for new dwellings. As we show in section 5.3, however, they do affect the size of the dwellings that are constructed.

As discussed in section 3, only limited regional age-specific data are available.

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[12] If 100 people moved into an area over a year, the one-year period regression indicates an overwhelming majority of the building permits are issued within three years of the population increase.

Prior to 2006, the only data come from censuses, which restricts us to analysing the relationship between building activity and population change over five-year periods. Four age groups are available: 0 – 14; 15 – 39; 40 – 64; and 65 plus.

Table 4 shows the average contribution of each age group to the population change in each region over the twenty-year period. Across the country, 6% of the 960,000 population increase occurred in the 0 – 14 age group, 16% in the 15 – 39 age-group, 50% in the 40 – 64 age-group, and 28% in the over 65 age-group. Auckland's population change was very different than that which occurred in most of the rest of the country. Auckland had much larger increases in the number of children and younger adults (people aged 15 – 39), and a relatively small increase in the number of people aged over 65. In total, 46% of Auckland's population increase between 1996 and 2016 was aged less than 40; in contrast, the number of people aged less than 40 declined in 9 out of the 16 other regions. Of the other regions, only Canterbury and to a lesser extent Wellington had a substantial increase in the number of people aged under 40.

Does Auckland's distinctive demographic profile explain why so few houses were constructed in Auckland relative to its population increase? The estimated regression results, which are displayed in table A1 in the appendix, do not support this contention. Unfortunately, the coefficient estimates have high standard errors, due to the high degree of correlation between the different demographic variables. This means in most circumstances it is not possible to reject the hypotheses that individual demographic variables contribute no additional explanatory power to the regressions, even though the estimated coefficients sometimes appear very different. These regression results tend to suggest that the number of new building permits appears to respond to total population change, not the individual components.

The demographic data are used to see if the population age-structure affects the size of newly constructed dwellings in section 5.3. These results are stronger, and suggest that regions with more young people build more small dwellings and more very large dwellings. Our tentative conclusion, therefore, is that while the age-structure affects the size of newly constructed dwellings, it does not have much effect on the overall number of dwellings. In particular, we have found no evidence that the young average age of Auckland's new residents can explain why so few new dwellings have been built. If anything, our estimates suggest that ignoring age-specific information understates Auckland's housing shortfall.

5 Differences in New Housing Size Across Regions

The average size of new dwellings in New Zealand increased from 133 m^2 in 1990 to 191 m^2 in 2016. This is a faster rate of increase than occurred in either Australia or the United States.[13] In Auckland the fraction of newly constructed dwellings smaller than 150 m^2 fell from 68 percent to 32 percent, while the fraction over 250m^2 increased from 8 percent to 26 percent. These figures raise two questions: why did the size of new houses increase; and is the increased size of houses a major factor behind Auckland's housing shortage? The answer to the first question is unclear, for the statistical evidence is not strong enough to untangle the relative importance of different factors. In contrast, the data clearly show that Auckland's housing shortfall *relative to the rest of the country* was not primarily because Auckland builders specialized in building large houses. Although the size of new housing in Auckland mirrored trends in the rest of the country, more small houses, primarily apartments, were built in Auckland prior to 2005.

5.1 The size distribution of new construction: a theoretical overview

The classic analyses of the markets for different quality houses were developed separately by Sweeney (1974) and Rosen (1974). Their analyses show that housing markets require the simultaneous consideration of (i) heterogeneous housing quality, (ii) a housing demand function that depends on rents, current house prices, the expected rate of change of house prices in the future, and other factors such as the number of people in the local housing market, their income, interest rates and taxes, (iii) knowledge of how

[13] New Zealand data are from Statistics New Zealand, "Number, value and floor area by building type, nature and region" BLD075AA. Australian data are from the Australian Bureau of Statistics, "Building Approvals" February 2010 8731.0 (The series is no longer produced.) U.S data after 1999 are from the website http://www.census.gov/construction/chars/completed.html spreadsheet " SFForSaleMedAvgSqFt". Earlier data are from http://www.census.gov/construction/chars/historical_data/ . This site has a series of books with the data e.g. US Department of Commerce (2000) "Characteristics of New Housing 1999".

households form expectations about future house prices, (iv) a supply function for new construction that is inelastic and subject to capacity constraints, and (v) a rule that decides the order in which houses differing in terms of quality are built when the demand to build is unusually high.

Sweeney's model calculates a long-run market equilibrium that depends on long-run supply and demand factors for houses that differ in terms of their quality, and a set of transition paths to this equilibrium. He observed that the demand for one quality of housing depends on the prices for all quality types, as buyers make price/quality comparisons and buy the quality type that offers them best value. In the long run, prices must reflect production costs to ensure positive amounts of each quality level are supplied. Consequently, the quantity of housing of each quality type depends on the demand for each type of housing when prices are equal to long-run production costs.

New housing is built for one of three reasons: (i) to maintain the quality of the old stock of housing, via alterations of the existing stock and replacement of houses as they depreciate; (ii) to improve the quality of the housing stock in response to changes in demand factors; and (iii) to increase the number of houses in the face of population growth or changes in the demographic composition of the population.[14] Unfortunately, very little can be said on how the quality profile of newly constructed houses depends on fundamental economic factors, as this profile is essentially the residual between the quality profile of the desired stock of housing and the quality profile of the existing stock of housing. Nonetheless, housing markets can be away from their long-term equilibrium for long periods if there is a large demand shock. During this time builders slowly alter the number of houses across the entire quality distribution, closing supply-demand mismatches that are reflected by prices which deviate from their long-term levels.[15]

[14] In the absence of population growth or factors changing the desired quality of the housing stock, the quality level of new construction tends to be higher than the existing stock. This is because a large fraction of the supply of lower-quality housing comes from the depreciation (or "filtering") of better-quality housing through time. New lower-quality housing is most likely to be built in fast growing cities, for they lack a sufficient stock of depreciated older dwellings to house lower-income households. Even in these circumstances new housing is likely to be disproportionately better quality, as large numbers of new higher-income (or higher-wealth) residents compete for the available stock of higher-quality houses.

[15] Suppose there is an increase in incomes that induces a demand for better quality dwellings across the whole quality distribution. This creates a mismatch between the quality of the

New Zealand experienced a large number of economic and demographic changes that increased the demand for better-quality housing after 1990. There was a substantial increase in household incomes after 1994, particularly amongst better-paid workers.[16] Real interest rates declined sharply after 2000, in line with international trends, reducing the user cost of durable assets including housing. There was a substantial decline in inflation following the Reserve Bank Act (1989), leading to even larger declines in nominal interest rates and thus a reduction in the effects of mortgage "tilt".[17] There were significant changes made to the way that retirement income accounts were taxed in 1989, providing a tax incentive to purchase larger houses as owner-occupied housing became a tax advantaged asset class (Coleman 2017). Finally, an increase in the fraction of the population aged 40 – 65 is likely to have increased the demand for larger houses (Coleman 2014).

While these factors should have affected all regions of the country, the effect of population growth on the desired quality of houses should have varied across regions. Builders in regions with low population growth mainly had to

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desired housing stock and the existing housing stock, and prices increase to match current demand with the available supply. The extent that prices need to increase depends on the extent that future prices are expected to reduce. When expectations are rational, and the supply imbalance is small, a small price increase may be sufficient to equate demand with the available supply, as expected future price declines will reduce contemporaneous demand. If expectations are not rational, or the demand imbalance is very large, large price increases may be necessary to reduce demand to match the available supply. When the total increase in demand is much greater than the available building capacity prices can remain higher than ordinary construction costs for some time, raising profit margins. In response to the increases in prices associated with the additional demand, the most profitable types of houses are built first: these are houses at quality levels where the gap between prices and construction costs is largest. Second hand prices can remain above long-term construction costs for lengthy but ultimately temporary periods of time as the quality composition of the housing stock is modified.

[16] Ministry of Social Development (2014) Incomes Report p13. Median household incomes increased by 45% between 1994 and 2014. Much of this was due to higher female participation. Real ordinary time incomes only increased 24% during this time.

[17] Holding real interest rates constant, an increase in the inflation rate raises nominal interest rates and the amount of nominal mortgage repayments. The real value of payments made at the beginning of a standard table mortgage is 'tilted' to be much higher than the real value of payments made at the end of the mortgage. As the contractual form of mortgages prevents households from borrowing to make these higher nominal payments, credit constrained households will find themselves unable to borrow as much as they would like. A decline in nominal interest rates will reduce the effect of these credit constraints and lead to a demand for better quality housing. See Kearl (1979).

alter the quality profile of the existing building stock. In contrast, builders in regions with large population increases had to cope with increased demand for larger houses from their incumbent populations, and the increased demand for houses across the whole quality distribution due to the influx of new people. The extent that the construction industry concentrated on one quality level rather than another is an empirical matter that reflects the differences between the cost of new housing and the second-hand price of old housing along the quality scale. In turn, the extent that prices remain above long-term levels depends on the size of the construction sector relative to the housing shortfall.

5.2 Alternative measures of Auckland's housing shortfall

Did Auckland's housing shortfall occur because builders in Auckland constructed unusually large houses over the period? There are several ways this question can be answered, all of which suggest the answer is "no". But fundamentally, the average size of new houses in Auckland would be larger than those built in the rest of the country if Auckland had built unusually large houses. In fact, the average size of new Auckland houses was 6 m^2 smaller than the average recorded in the rest of the country, 177 m^2 versus 183 m^2.

Table 5 shows the results of a set of regressions that use different metrics to measure Auckland's housing shortfall. The first half of the table includes the total area and the real value of housing permits, the real value of permits for alterations, and the total value of permits, new housing plus alterations. The second half of the table reports the results for the number of permits in three different size classifications: small dwellings less than 150m^2, medium sized dwellings from 150 – 250 m^2, and large dwellings in excess of 250m^2. The table reports the results of the regression used in section 3, but modified for different dependent variables, along with the forecast Auckland shortfall over the entire period:

$$BP_{it}^{a} = \alpha_0^a + \alpha_1^a region\ dummy_i + \alpha_2^a time\ dummy_t + \alpha_3^a Christchurch + \alpha_4^a \Delta Popn_{it} + e_{it}^a \qquad (17)$$

where BP_{it}^{a} is a particular measure of building activity in region i during period t.

Each regression includes a full set of regional and time dummy variables. The regressions are estimated using the 15 regions excluding Auckland, and use data aggregated into either three-year or four-year periods. The table contains the level and standard errors of the estimated coefficients $\hat{\alpha}_4$, the R^2 of the regression, the estimated serial correlation of the errors, and the estimated shortfall (or surplus) in Auckland made under the assumption that the value of the regional dummy for Auckland is equal to the average regional dummy variable. The coefficients are estimated using ordinary least squares and the standard errors are calculated using the Huber-White method.

The first row of the table shows the results when the dependent variable is the number of building permits per capita per year, using four-year intervals estimated over the period 1997 – 2016. This is the regression reported in row 3 of table 2, and the coefficient has the interpretation that each additional person in a region is associated with the construction of 0.235 additional houses. By this metric, Auckland's shortfall was estimated to be 53,400 dwellings over the period 1996 – 2016. In the second row, the dependent variable is the total area of new construction per capita per year. The regression indicates that an additional person is associated with an extra 39 m^2 of construction, and that Auckland had an accumulated shortfall of 9,950,000 m^2 between 1996 and 2016. As the average newly constructed house in New Zealand over the period was 183 m^2, this is equivalent to a shortage of 54,400 dwellings, very similar to the previous estimate. The accumulated shortfall means that the total area of permits issued in Auckland was 27 percent less than required to keep up with construction trends elsewhere in the country.[18] In the third row, the dependent variable is the real per capita value of housing permits issued each year. The coefficient indicates that outside Auckland each additional person in a region is associated with an additional $60,800 worth of construction (in 2016-dollar terms.) Auckland is estimated to have had an accumulated shortfall of $11.8 billion over the twenty-year period, in 2016-dollar terms. If construction costs in Auckland were the same as those in the rest of the country, Auckland's shortfall would imply a shortage of 35,000 dwellings. Auckland's construction prices per square metre were on average 7 percent higher than those in the rest the country, however; this means the estimated shortfall is more likely to be 44,600 dwellings.[19] Once again, this

[18] Permits with a total area 26,400,000 m^2 were issued in Auckland during the period.

[19] The real dollar amount of building each year in Auckland is reduced by 7% and then compared with an estimate of the value of housing Auckland should have built based on its population growth.

estimated shortfall confirms that Auckland's housing shortfall did not occur because of the construction of excessively large or better quality houses than those in the rest of the country.

The additional construction associated with an additional person is more than New Zealand's per capita GDP, which in 2016 was $54,178. For the country as a whole, this means that unusually high inward migration will be hyper-expansionary, as the immediate demand for housing by immigrants exceeds their productive potential. For this reason, the short term impact of population increase may be to increase labour demand by more than labour supply, potentially causing labour shortages and placing upward pressure for additional inward migration. As such, these estimates appear to support Belshaw's (1955) and Gould's (1982) arguments that high levels of inward migration to New Zealand cause rather than alleviate labour shortages.

The last two rows in the top half of the table examine alterations of existing houses. To a first approximation, it might be expected that the quantity of alterations would mainly depend on the existing stock of houses, not the change in population. In practice, however, there is a statistically significant positive relationship between the change in population and the real value of permits for alterations, although the size of the relationship is relatively modest: alterations increase by $5520 (in 2016 dollar terms) for each additional person in a region. This suggests people are more likely to alter their houses when the local population is increasing rapidly, possibly because it is more economic to alter an existing house than it is to compete with new residents to move into a different house. Auckland had more permits for alterations than would be expected given its population growth, although the extent of the surplus is modest, totaling approximately $200 million over the period.[20] This is a much smaller amount than the $11.9 billion shortfall in newly constructed housing, indicating the shortfall did not occur because builders were engaged altering existing houses. This is shown formally in the last row of the section, which regresses the total real value of building permits (alternations plus new houses) against population change. The estimated coefficient suggests an additional person in a region is associated with $66,000 of new construction and alterations.

[20] The small size of Auckland's additional alterations is surprising, as the average value of each alteration is nearly twice as big as the value of alterations in the rest of the country, possibly reflecting the very expensive alterations required by the leaky house fiasco.

A different perspective on Auckland's shortfall is obtained by examining permits disaggregated by size (the last rows of table 5). The estimated coefficients for the rest of the country indicate that for each additional 100 people in a region, permits for 9.7 small (< 150 m^2), 9.8 medium sized (150 – 250 m^2) and 2.7 large (>250 m^2) dwellings were issued. (These ratios changed over time, with fewer small dwellings and more large dwellings as time progressed.) This means that between 1996 and 2014 Auckland had a shortfall of 8,700 small dwellings, 27,800 medium sized houses, and 6,600 large houses. The shortfall was relatively smallest for small dwellings and largest for medium sized buildings.

Figure 4 shows the estimated shortfall of dwellings through time. The data show that Auckland was building more small dwellings than could be expected given its population growth until 2005, but fewer medium and large dwellings. After 2005 there is a major decline in the construction of small dwellings, but little change in the annual shortfall of other dwellings. It appears, therefore, that the acceleration in Auckland's housing shortfall after 2005 stems from a major decline in the rate that small dwellings were constructed.

The acceleration in Auckland's housing shortfall after 2005 can be pinpointed not just to the decline in the construction of small dwellings, but to the collapse of the construction market for central city apartments. Figure 5 shows indices of the number of permits for stand-alone houses and all other dwellings (apartments, retirement home units for independent living, town-houses and other such units) in both Auckland and the rest of New Zealand. The data indicate that the number of permits for units and stand-alone houses track each other quite closely in New Zealand outside Auckland. The number of permits for houses in Auckland also has similar trends, except there was noticeably more building permits issued prior to 2005 than after 2005. The construction of other units in Auckland followed a very different pattern, however. There was a boom in construction between 2002 and 2005, followed by an almost complete collapse of new construction between 2009 and 2012.

Figure 6 traces this further by showing building permits for houses, apartment units, and other units in the five wards that comprise central Auckland.[21] There were 11251 building permits for apartments in central Auckland in the three years between July 2002 and June 2005; in contrast, only 786 were issued

[21] North Shore, Waitemata, Albert-Eden-Roskill, Orakei and Maungakiekie wards.

from July 2008 to June 2012. Between 2002 and 2005 central Auckland apartments comprised 17.6 percent of all permits issued in New Zealand; from 2009-2012 they were only 1.6 percent. Whether these data are interpreted as evidence that the apartment building boom largely prevented Auckland from having a serious housing shortfall prior to 2005, or evidence that the collapse in Auckland's apartment market is a large component of why Auckland has an acute housing shortfall, is perhaps a matter of choice. Either way, the data suggests that understanding the collapse of central Auckland's new apartment market may be as important as understanding Auckland's suburban land-use issues.

In 2015 the New Zealand Productivity Commission conducted an extensive enquiry into the operation of New Zealand's land markets (New Zealand Productivity Commission (2015)). They argued that regulation changes introduced in Auckland in 2005 concerning the minimum floor size, the availabilities of balconies, stud height, the overall size of a building, and the sight-lines all sparked the collapse of apartment building in Auckland, partly because they significantly raised the price at which apartments could be profitably sold. Grimes and Mitchell (2015), on the basis of interviews with developers came to similar conclusions. We have no reason to disagree with their conclusions. Nonetheless, these regulations may not have been the only factor. Much of the finance for these apartments was obtained from finance companies. Beginning in 2006 and 2007, investors in finance companies began to doubt the quality of the assets of the sector, resulting in a collapse of more than 50 companies and large losses to depositors. [22] As standard economic theory suggests that a collapse of financial intermediation can lead to significant reductions in investment activity, it is possible that the collapse of these finance companies may be part of the reason for the subsequent collapse in new apartment construction.[23] Since this hypothesis has not been comprehensively explored in this context, it warrants further investigation.

5.3 Population change and the size of new houses

How do population and demographic change affect the size of newly constructed houses? We use two approaches to explore the issue. First, we

[22] Between May 2006 and 2012 67 finance companies collapsed in New Zealand. Many of these had financed new property developments. For more details and references to sources, see https://en.wikipedia.org/wiki/Finance_company_collapses,_2006_2012_(New_Zealand)

[23] For an example of this literature, Radelet and Sachs (1998) examine how liquidity crises affected construction during the Asian economic crisis of 1997-1998.

examine how the size of newly constructed houses varied with the population growth rate across regions, by comparing the size distribution of newly constructed houses in regions with positive population growth with the size distribution of newly constructed houses in the four regions with no population growth. Secondly, we use the variation in age structure across regions to see whether the age of new residents in a region affects the size of newly constructed houses.

There were four New Zealand regions that had near zero population growth between 1996 – 2016: Gisborne (+1.3%), Wanganui-Manawatu (+1.0%), West Coast (-2.1%), and Southland (-1.0%). In 2016 these regions had a total population of 415,000. Over the twenty-year period, the four regions issued 23587 building permits, which amounts to 2.8 per 1,000 people per year.[24] The rate varied little through time, and the size-distribution of building permits was remarkably constant through time (see table 6). This baseline 'zero-growth' distribution can be subtracted from the distributions of high-population growth regions to calculate the distribution of house sizes associated with population growth. We present results for the size distribution of newly constructed houses between 1996 and 2006.[25]

Following the U.S. literature, we have divided the regions with high population growth rates into two groups. One set is fast growing cities with desirable consumption amenities, such as a warm climate or a coastal location, but low average incomes. These so-called 'sun' cities are attractive to older people (Chen and Rosenthal 2008; Partridge 2010; Fodor 2010). The second set is fast growing cities with attractive business amenities, which offer high incomes and tend to be attractive to younger, highly educated people. Grimes et al (2016) demonstrated that many New Zealand cities can be classified in this manner, as many of New Zealand's fastest growing regions are

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[24] The average rate in the West Coast, 4.6 per 1000, was higher than elsewhere. This may reflect the region's popularity as a holiday home destination.

[25] Between 2007 and 2014 the amount of construction activity in Auckland and Wellington was scarcely higher than the amount in the zero-population growth regions on a per capita basis. This means it is not practical to estimate the marginal distributions for these regions during this period. The marginal size distributions for the other regions can be estimated but as they are similar to those from the 1996-2006 period we have chosen not to present these results. Northland is the main region where the size distribution changed significantly over time; the average size of newly constructed houses increased appreciably between 1996-2006 and 2007 – 2014. We have not presented results for regions with low but non-zero population growth rates, such as Otago, as the marginal distributions cannot be accurately estimated.

characterized by high sunshine levels, lower-then-average incomes and a relatively old population structure. New Zealand's 'sun' regions include Northland (the region with the lowest per capita GDP in New Zealand in both 2000 and 2016), Waikato, Bay of Plenty, Tasman and Nelson. These regions had significantly more building activity than the zero-growth regions throughout the period. The marginal building-permit/population distributions for all these regions (except Northland) are sufficiently similar that we have aggregated them together. The two prominent business regions are Auckland and Wellington.

Figure 7 shows the marginal distribution of building permits by size in different regions in 1997 – 2006. Two aspects of the distributions stand out. First, fewer large houses and more medium sized houses were built in the 'sun' regions than were built in the zero-growth regions. This is consistent with the hypothesis that the large-scale construction of very large houses in the zero-growth regions is a disequilibrium phenomenon, as the available stock is increased to match the desired stock. The 'sun' regions also built fewer small houses than the zero-growth regions. We are unable to ascertain whether this reflects the higher average incomes in the 'sun' regions or because the population increase in the sun regions largely reflects an increase in the number of older and typically wealthier people.

Secondly, Auckland and Wellington had a much larger proportion of newly constructed small dwellings than either the 'sun' regions or the zero-growth regions. In both cases the large number of building permits for small dwellings reflects the construction of apartments in the central city. The Auckland and Wellington results do not reflect income differentials, as both cities have higher income levels than the 'sun' regions. Rather, as we show below, the difference between Wellington and Auckland and the other regions partly reflects differences in the age profile of the new residents, for the increase in Auckland's and Wellington's populations was disproportionately in young age groups. The demand for small dwellings may also reflect high land prices in Wellington or Auckland, and the greater advantages of living close to the centre of these cities.

Figure 7 also shows the distributions for Northland and Canterbury. Northland, New Zealand's poorest region, built smaller houses than the zero-population regions. The marginal distribution for Canterbury is similar to that of the 'sun' regions, with fewer small houses and greater number of middle-sized houses than the distributions in the zero-population regions.

It was demonstrated in section 4.3 that the population increase in Auckland was much younger than the population increase in the rest of the country. While we failed to find evidence that the age structure of the population affected the total demand for construction, to ascertain if it affects the size of newly constructed houses we estimated the following regressions:

$$BP_{it}^{\alpha} = \alpha_0^5 + \alpha_1^5 region\ dummy_i + \alpha_2^5 time\ dummy_t + \alpha_3^5 Christchurch + \sum_{k=1}^{4} \beta_k^5 \Delta Popn_{it}^k + e_{it}^5 \qquad (18)$$

$$BP_{it}^{\alpha} = \alpha_0^5 + \alpha_1^5 region\ dummy_i + \alpha_2^5 time\ dummy_t + \alpha_3^5 Christchurch + \gamma_0^5 \Delta Popn_{it}^{tot} + \gamma_k^5 \Delta Popn_{it}^k + e_{it}^5 \qquad (19)$$

where

BP_{it}^{α}	is the number of building permits of a particular size issued during a five-year period
$\Delta Popn_{it}^k$	is the population change in age group k in region *i* during period *t*, as a fraction of the initial total population of that region.

The results are presented in table 7. Two features stand out. First, the number of newly-constructed small houses (< 150 m^2) appears to be positively correlated with the number of new residents aged 15 – 39 and negatively correlated with the number of new residents aged more than 65. The number of people in these two age-groups is strongly and negatively correlated, so it is difficult to determine whether the relationship is causal. This correlation is consistent with the large number of small dwellings built in Auckland and Wellington, as these cities had relatively large increases in the number of young people and relatively small increases in the number of older people. Secondly, the number of large newly constructed houses (> 250 m^2) is positively correlated with the number of new residents who are under 15 years old and the number of people who are aged 15-39, and negatively correlated with the number of people who are aged 40-64 and the number of people who are aged over 65. Again, the causality is difficult to untangle due to the negative correlation between the number of people in each of these age-groups.

Overall, this analysis is less revealing than hoped. There appear to be significant differences in the demand for small houses in Auckland and

Wellington and the rest of the country, with demand higher in the fast growing high-income cities than the fast growing lower-income 'sun' regions. It is plausible that the differences between Auckland and Wellington and the rest of the country reflect the increase in the number of young people in these cities. In Auckland, and to a lesser extent Wellington these demands were met through apartment units. The collapse of new apartment construction in Auckland appears to be a key difference in the post 2006 building patterns of Auckland and the other fast growing regions. Since apartment construction seems to be the main method through which smaller sized housing is delivered to Auckland households, properly understanding the reasons for its collapse, and its current resurgence, is a key issue.

6 Population Growth and the Number of Builders

The previous sections have demonstrated the extent that population growth leads to greater amounts of construction activity. The estimates suggest each new arrival in an area is associated with $66,000 additional construction activity; naturally, much of this will be spent employing local construction workers. For this reason, areas with higher population growths should specialize in construction activity.

Figure 9 plots the average fraction of the workforce who were employed in the residential construction sector by region against the average population growth by region between 2001 and 2016.[26] The data clearly indicate a linear relationship between population growth rates and the fraction of the workforce in the construction sector – and also indicate Auckland has fewer construction workers than would be expected given their population growth rate.

Table 8 reports the estimates of the regression

$$\begin{aligned} BF_{it}^{h} &= \alpha_0^h + \alpha_1^h \textit{region dummy}_i + \alpha_2^h \textit{time dummy}_t + \alpha_3^h \textit{Christchurch} \\ &\quad + \alpha_4^h \Delta Popn_{it} + e_{it}^h \end{aligned}$$

[26] Residential construction workers are construction workers excluding those in the heavy-construction sectors (e.g. road-building and commercial development.) These are sectors E30 and E32 of the Business Demographic Statistics.

where BF_{it}^{h} is the fraction of the workforce employed in the construction sector (E30 and E32) in region *i* during period *t*, and *h* refers to the length of the period in years.

The equations are estimated using ordinary least squares and feasible generalized least squares, the latter to take into account first order serial correlation in the error process.

Results are reported for the regressions using period lengths varying from one to eight years. We prefer the longer horizons as the number of builders is not likely to be particularly responsive to fluctuations in population numbers in the short run, as additional work can be delayed into subsequent periods. The estimates in table 8 exclude Auckland, but are used to estimate the shortfall of builders in Auckland. (If Auckland data are included in the regressions, the coefficients are slightly higher, and estimated more accurately.)

The estimates suggest that an additional 1 percentage point increase in the population growth rate is associated with a 0.5% increase in the fraction of construction workers in the workforce. If the population growth rate were zero, the fraction of construction workers in the workforce would average 4.3 percent. Therefore, regions with an average population increase of 1 percent per year should have about 10 percent more construction sector workers than zero-population growth regions. In concrete terms, rapidly growing Tauranga should have nearly 600 construction workers more than Dunedin, even though the cities have the similar populations (120,000). These estimates do not include construction workers who work in heavy industry or infrastructure projects.

The estimates suggest Auckland would have 1 percent more of its workforce, or about 9000 workers, if it employed construction workers at a rate similar to that of the rest of the country. Land restrictions may be part of the reason why Auckland constructs many fewer houses than would be expected given its population growth rate, but even if these were solved there would need to be a substantial increase in the number of builders working in Auckland to build houses at the rate they are being constructed in the rest of the country.

As noted earlier, in recent years many of the regions with faster population growth in New Zealand (and to a greater extent in the United States) have lower than average incomes, and appear to be growing because of the superior natural amenities they offer. These estimates suggest, perhaps obviously, that one of the key differences between population-stagnant regions of the country and rapidly growing regions is that the latter specialize in construction. At a regional level it is unclear whether this additional activity comes at the expense of other non-tradeable or tradeable activities. At a national level, however, standard economic theory suggests rapid population growth should be associated with lower current account surpluses or larger current account deficits unless saving rates rise commensurately with investment rates. The deterioration in the current account occurs either because of rising imports or because of a diversion of workers from export-sector firms to construction sector firms. Given that New Zealand's population growth has been disproportionately concentrated in the Auckland and the 'sun' regions, it is an intriguing question whether the struggles of some traditionally exporting regions may be associated with the rising demand for construction workers in regions experiencing rapid population growth.

7 Conclusions

Using regional variation in population growth rates we have investigated how population growth affects residential construction across New Zealand regions. We find that an additional person in a region is associated with 0.25 new houses or $65,000 (2016 dollars) new construction including new consented alterations. Indeed, population growth is so strongly associated with construction activity that international and interregional migration may be hyper-expansionary, as the short run demand associated with each additional person is greater than their average level of output.

We use our estimates to back-out Auckland's housing shortfall and find that if Auckland had built houses at the same rate as the rest of the country (adjusted for population growth) it would have needed an additional 45,000 – 55,000 dwellings during the 1996-2016 period. The reasons for this shortfall are unclear, but may reflect the impact of land-use restrictions imposed after 2005. Even if land-use restrictions were solved, Auckland has such a shortage of construction workers relative to the rest of the country that it may need 9000 more construction workers to meet its ongoing demand for new houses.

Auckland's housing shortfall was modest until 2005, but sharply accelerated when apartment building effectively ceased in between 2008 and 2012. When we decompose the overall shortage in terms of house sizes we find that Auckland had a shortfall of 8,700 small dwellings (< 150 m^2) by 2014, 27,800 medium sized houses (150 – 250 m^2), and 6,600 large houses (>250 m^2).

Finally, we have documented the change in the size of newly constructed houses over the period. Some of the variation in the size of new houses across different regions reflects demographic differences, although these differences do not appear to be a major factor in overall construction rates. It is noteworthy that Auckland's population increase was much younger than other regions, which may explain the disproportion number of small dwellings that were built between 1996 and 2006. Since the increase in the average size of new dwellings was less in Auckland than elsewhere, it does not appear to have been a major factor behind the shortage of houses in Auckland relative to the rest of the country.

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Table 1

Population growth and construction activity in New Zealand, 1996 – 2016

	Auckland	Rest of New Zealand	New Zealand
1996 Population	954,000	2,616,000	3,732,000
2016 Population	1,614,000	3,078,000	4,693,00
Change	499,000	462,000	961,000
Building permits	153,000	304,000	456,000
Population Change/ Building Permits	3.26	1.52	2.10

Table 2
Regression results - Number of building permits per capita versus regional population growth

	$\hat{\alpha}_4 \Delta Popn_{it}$ (s.e.)	t-stat	R^2	$\hat{\rho}$ (se)	obs	Auckland shortfall, 2016
Without Auckland in the sample						
h =1 year	0.182 (0.013)	13.3	0.84	0.573 (0.04)	300	-38,600
h =2 years	0.198 (0.018)	10.8	0.87	0.30 (0.08)	150	-43,300
h = 4 years	0.235 (0.027)	8.6	0.90	-0.12 (0.12)	75	-54,400
h = 5 years	0.217 (0.032)	6.7	0.88	-0.26 (0.14)	60	-47,600
h =10 years	0.240 (0.025)	9.5	0.92	N/A	30	-55,300
h =20 years	0.343 (0.051)	6.6	0.77	N/A	15	-84,500
With Auckland in the sample						
	$\hat{\alpha}_4 \Delta Popn_{it}$ (s.e.)	t-stat	R^2	$\hat{\rho}$ (se)	obs	Auckland shortfall, 2016
h =1 year	0.191 (0.013)	14.6	0.83	0.57 (0.04)	320	-38,300
h =2 years	0.210 (0.017)	11.9	0.86	0.30 (0.07)	160	-43,800
h = 4 years	0.247 (0.025)	9.7	0.89	-0.09 (0.11)	80	-53,700
h = 5 years	0.233 (0.030)	7.5	0.88	-0.23 (0.13)	64	-49,100
h =10 years	0.265 (0.026)	10.0	0.92	N/A	32	-59,400
h =20 years	0.259 (0.051)	5.0	0.65	N/A	16	-52,800

Table 3
Regression results- Number of building permits per capita versus regional population growth

	$\hat{\alpha}_4 \Delta Popn_{it}$ (s.e.)	$\hat{\alpha}_5 \Delta Popn_{it-1}$ (s.e.)	$\hat{\alpha}_6 \Delta Popn_{it-2}$ (s.e.)	$\hat{\alpha}_7 \Delta Popn_{it-3}$ (s.e.)	R^2	$\hat{\rho}$ (s.e.)	obs	Auckland shortfall, 2016
h =1 year	**0.132 (0.018)**	**0.075 (0.018)**			0.85	**0.55 (0.048)**	285	-45,000
h=1 year	**0.131 (0.018)**	0.033 (0.021)	**0.055 (0.018)**		0.86	**0.56 (0.050)**	270	-46,500
h=1 year	**0.136 (0.018)**	0.033 (0.020)	**0.056 (0.019)**	-0.001 (0.017)	0.86	**0.53 (0.054)**	255	-49,300
h=2 years	**0.166 (0.019)**	**0.061 (0.018)**			0.88	**0.24 (0.08)**	135	-49,100
h=2 years	**0.182 (0.018)**	**0.050 (0.018)**	0.023 (0.017)		0.89	**0.24 (0.09)**	120	-53,400
h=4 years	**0.256 (0.031)**	0.038 (0.023)			0.91	-0.15 (0.96)	60	-65,500

Note: Coefficients in bold are statistically significant at 5 percent.

Table 4
Population change by age in New Zealand's regions, 1996 - 2016

	Total	0-14	15 - 39	40 – 64	65+
New Zealand	961,100	62,000	149,800	481,100	268,200
		6%	16%	50%	28%
Northland	30,800	-800	-2,300	17,500	16,400
		-3%	-7%	57%	53%
Auckland	498,800	62,800	165,400	192,500	78,100
		13%	33%	39%	16%
Waikato	90,400	5,500	7,700	45,700	31,500
		6%	9%	51%	35%
Bay of Plenty	62,900	3,900	2,100	32,000	24,900
		6%	3%	51%	40%
Gisborne	700	-1,500	-2,500	2800	1,900
Hawke's Bay	15,000	-1,400	-7,100	12,700	10,800
		-9%	-47%	85%	72%
Taranaki	7,700	-2,400	-4,600	8,800	5,900
		-31%	-60%	114%	77%
Whanganui/Manawatu	2,200	-8,500	-17,000	14,700	13,000
Wellington	78,000	200	4,400	47,900	25,500
		0%	6%	61%	33%
Tasman	11,400	300	-1,400	7,100	5,400
		3%	-12%	62%	47%
Nelson	9,500	600	-1,200	6,300	3,800
		6%	-13%	66%	40%
Marlborough	6,200	-600	-2,000	4,300	4,500
		-10%	-32%	69%	73%
West Coast	-700	-2,000	-3,100	2,500	1,900
Canterbury	119,400	10,600	17,000	62,300	29,500
		9%	14%	52%	25%
Otago	29,900	-700	700	19,200	10,700
		-2%	2%	64%	36%
Southland	-1,100	-4,000	-6,300	4,800	4,400

Source: Authors' calculations from Statistics New Zealand data. The raw numbers are the changes in the number of people in the age group in a region; the percentages are the ratio of the change in the age-specific group relative to the total change in population.

Table 5
Regressions of building activity versus regional population growth

	$\hat{\alpha}_4 \Delta Popn_{it}$ (s.e.)	t-stat	R^2	$\hat{\rho}$ (se)	obs	Auckland shortfall, 2016	Equivalent dwellings
	Full sample, 1997 – 2016. Estimated over four year periods.						
BP numbers	0.235 (0.027)	8.6	0.90	-0.12 (0.12)	75	-53,400	
BP m^2	38.9 (5.1)	7.7	0.91	-0.16 (0.12)	75	-9,945,000 m^2	-54400
BP real value $2016	60800 (9900)	6.2	0.88	-0.15 (0.12)	75	-$11.9 billion	-35100*
Alterations Real $2016	$5520 (1380)	4.0	0.84	-0.27 (0.12)	75	+$195 million	
Alterations + BP real $2016	$66300 (11000)	6.0	0.88	-0.17 (0.12)	75	-$12.1 billion	
	Shortened sample 1997-2014. Estimated over three year periods						
	$\hat{\alpha}_4 \Delta Popn_{it}$ (s.e.)	t-stat	R^2	$\hat{\rho}$ (se)	obs	Auckland shortfall, 2014	% of total
BP < 150 m^2 Numbers	0.097 (0.01)	9.2	0.83	0.07 (0.10)	90	-8,700	20%
BP 150-250 numbers	0.098 (0.016)	6.1	0.87	0.09 (0.11)	90	-27,800	65%
BP > 250 m^2 Numbers	0.027 (0.01)	5.1	0.88	0.08 (0.11)	90	-6,600	15%
BP all sizes Numbers	0.22 (0.028)	8.0	0.89	0.04 (0.11)	90	-43,000	

Table 6
Distribution of building permits by size, zero growth regions, 1991 – 2014

	Permits per 10000 people				Distribution function		
	1992-1996	1997-2006	2007-2014		1992-1996	1997-2006	2007-2014
<100 m2	8.4	5.2	5.4		25.8%	18.7%	16.5%
100-150	9.2	5.2	6.9		28.4%	18.7%	21.2%
150-200	6.5	6.1	6.9		20.0%	21.9%	21.4%
200-250	4.6	5.3	6.1		14.2%	19.1%	18.9%
250-300	2.2	3.2	3.7		6.8%	11.3%	11.5%
300-350	0.8	1.5	1.6		2.5%	5.3%	5.1%
350-400	0.4	0.7	0.8		1.2%	2.4%	2.5%
400 +	0.3	0.6	0.8		1.0%	2.2%	2.4%
Total	32.5	27.9	32.4		100.0%	100.0%	100.0%

Annual building permits per 10000 people per year in Gisborne, Wanganui-Manawatu, West Coast and Southland.

Table 7
Regression coefficients between the size of new buildings and demographic variables

	Total population	0-14	15- 39	40 – 64	65+	R^2	F-test
	Dependent Variable: Number of small (< 150 m^2) building permits per capita						
1.1	0.107 (0.016)**					0.84	
1.2		0.063 (0.084)	0.168 (0.047)**	0.054 (0.048)	-0.161 (0.085)*	0.87	1.50
1.3	0.104 (0.027)**	0.013 (0.10)				0.88	0.02
1.4	0.016 (0.047)		0.181 (0.086) *			0.85	4.40*
1.5	0.107 (0.024)**			0.002 (0.061)		0.84	0.00
1.6	0.115 (0.014) **				-0.266 (0.083)	0.86	10.24**
	Dependent Variable: Number of medium (150 - 250 m^2) building permits per capita						
2.1	0.089 (0.015)**					0.89	
2.2		0.193 (0.092)	0.025 (0.057)	0.123 (0.080)	0.012 (0.125)	0.90	0.77
2.3	0.064 (0.030)*	0.092 (0.105)				0.89	0.76
2.4	0.124 (0.063)		-0.068 (0.114)			0.89	0.36
2.5	0.081 (0.042)			0.023 (0.097)		0.89	0.18
2.6	0.092 (0.014)**				-0.073 (0.133)	0.89	0.30
	Dependent Variable: Number of large (> 250 m^2) building permits per capita						
3.1	0.019 (0.0062)**					0.89	
3.2		0.072 (0.031)*	0.032 (0.02)	-0.065 (0.021) **	-0.125 (0.036) **	0.92	4.49*
3.3	-0.016 (0.013)	0.130 (0.043) **				0.90	9.18**
3.4	-0.033 (0.019)		0.105 (0.036) **			0.90	8.24**

3.5	0.034 (0.009) **			-0.073 (0.034) *		0.90	4.41*
3.6	0.023 (0.006) **				-0.11 (0.032) **	0.90	12.46**

Source: Authors' calculations using Statistics New Zealand data
In each case the F-test is a comparison of the restricted regression in row n.1 with the unrestricted regression in the subsequent row.
A ** indicates statistical significance at the 0.01 level; * indicates significance at the 5% level

Table 8
Regressions of the fraction of the workforce in the construction sector against population growth, 2000 – 2016

	$\hat{\alpha}_4 \Delta Popn_{it}$ (s.e.)	t-stat	R^2	$\hat{\rho}$ (se)	obs	Auckland shortfall, 2016
OLS estimates						
h =1 year	0.33 (0.09)	3.6	0.85	0.74 (0.05)	240	-0.8%
h =2 years	0.43 (0.17)	2.6	0.86	0.41 (0.10)	120	-1.1%
h = 4 years	0.47 (0.21)	2.2	0.84	-0.37 (0.18)	60	-1.0%
h = 8 years	0.49 (0.12)	4.0	0.94	-0.12 (0.12)	30	-0.9%
FGLS estimates						
h =2 years	0.43 (0.10)	4.4	0.86	0.41 (0.10)	120	
h = 4 years	0.47 (0.19)	2.5	0.84	-0.37 (0.18)	60	

Figure 1

Annual average building permits/ capita versus population growth 1996 - 2016

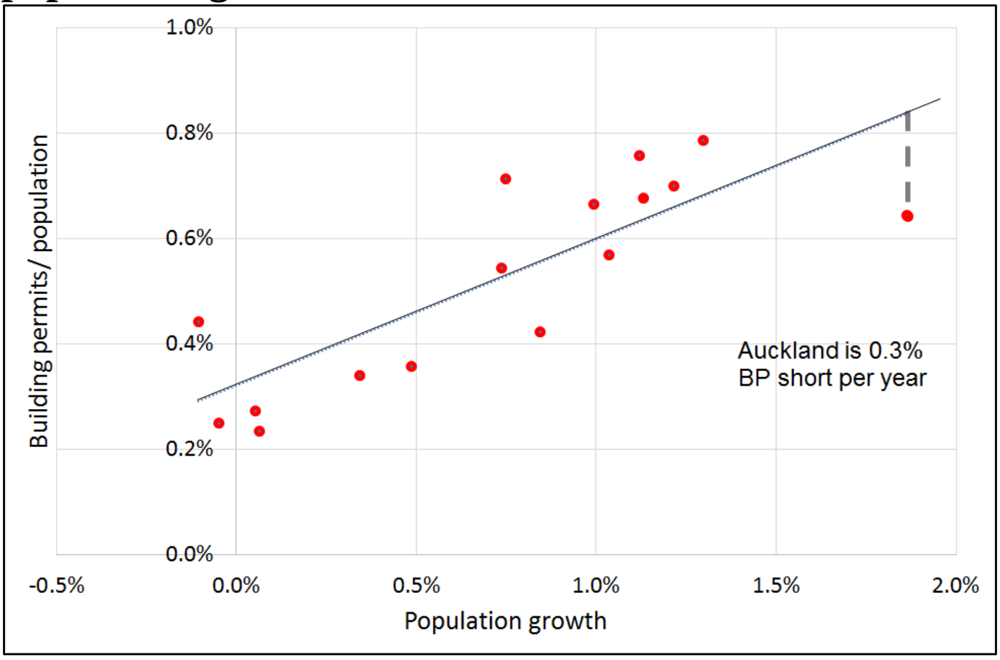


Figure 2
Estimates of Auckland's housing shortfall for different period length regressions

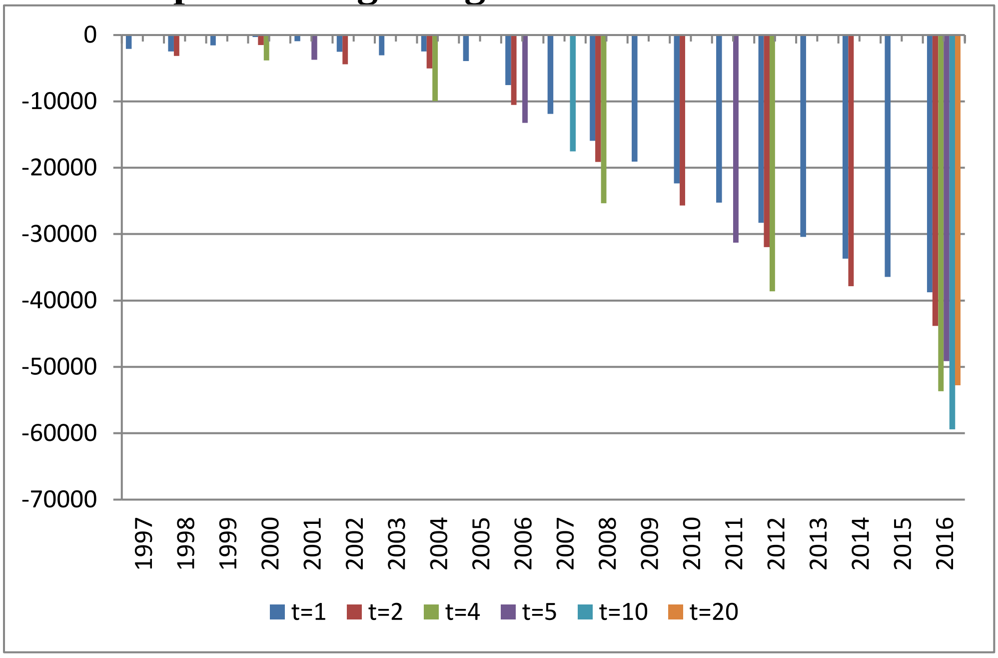


Figure 3
Auckland's accumulated housing shortfall , 1996 - 2016

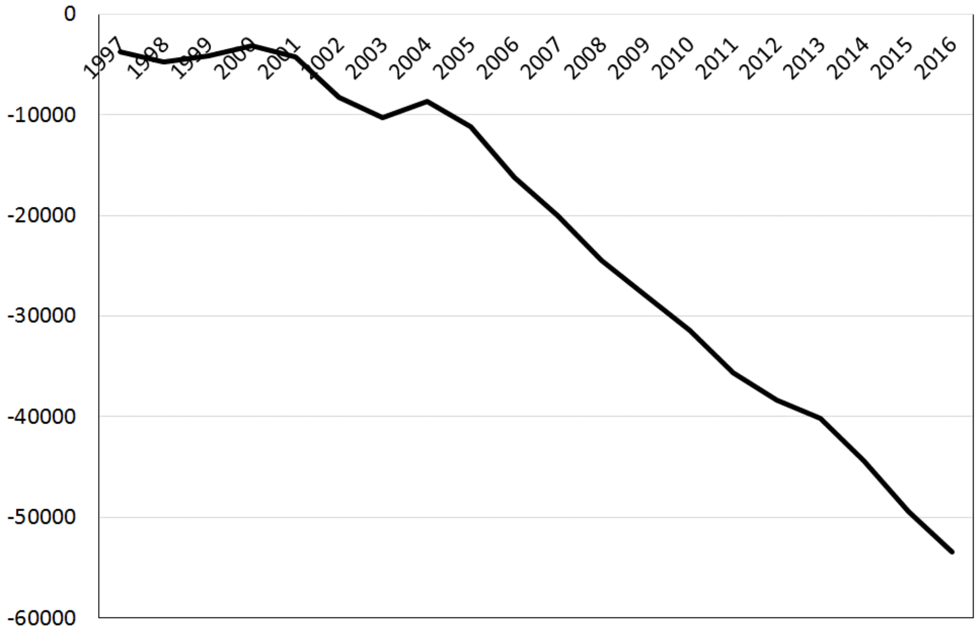


Figure 4
Estimated Auckland shortfall by size of dwelling, 1996 –2014

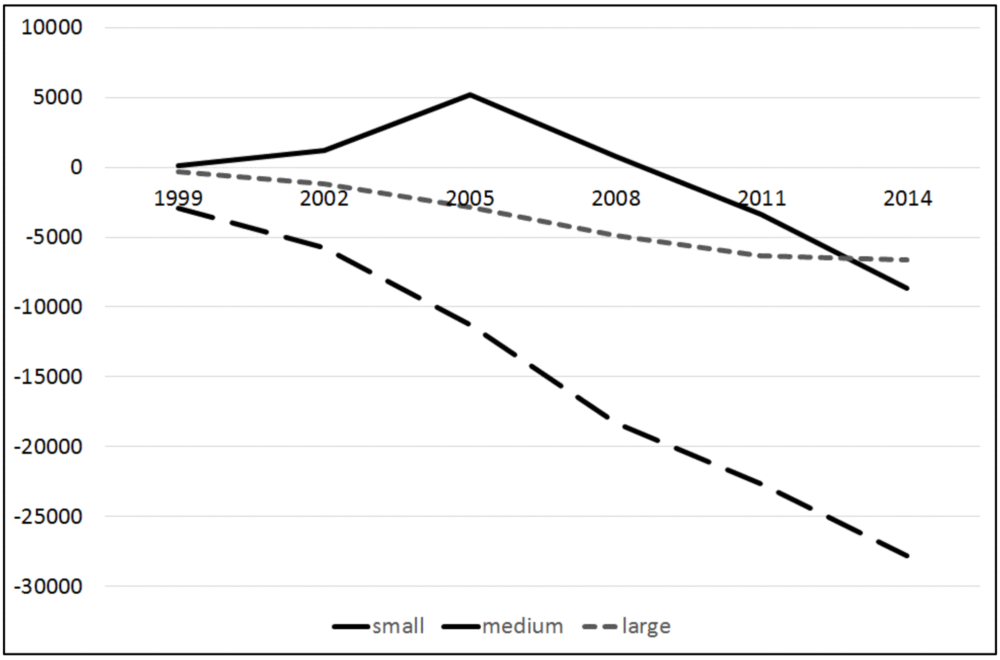


Figure 5
Index of Building Permits: Auckland and the Rest of New Zealand, 1991 – 2014

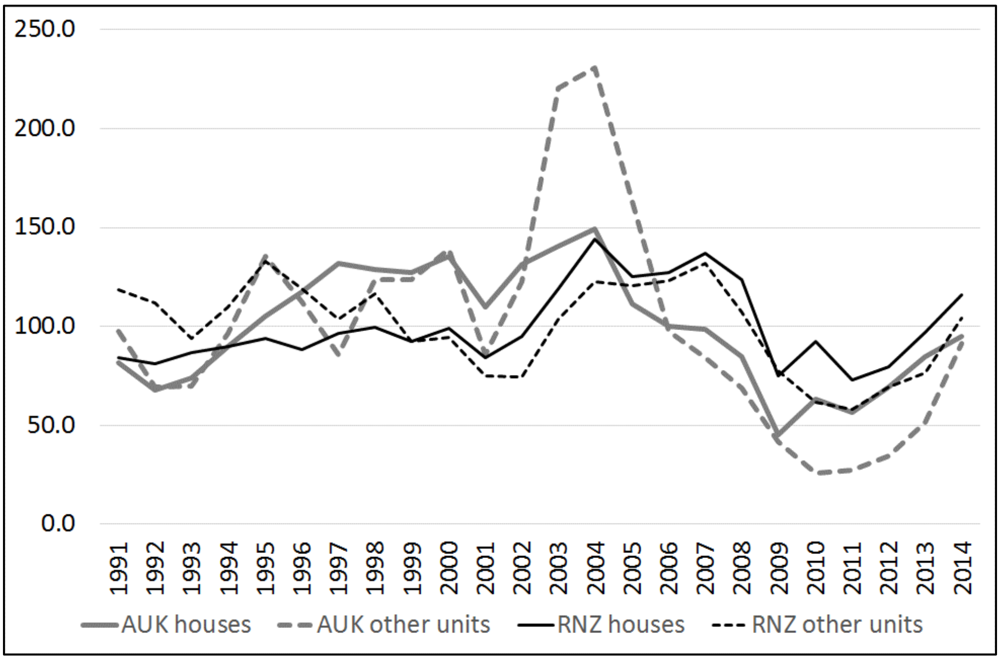


Figure 6
Central Auckland building permits, 1991 – 2014

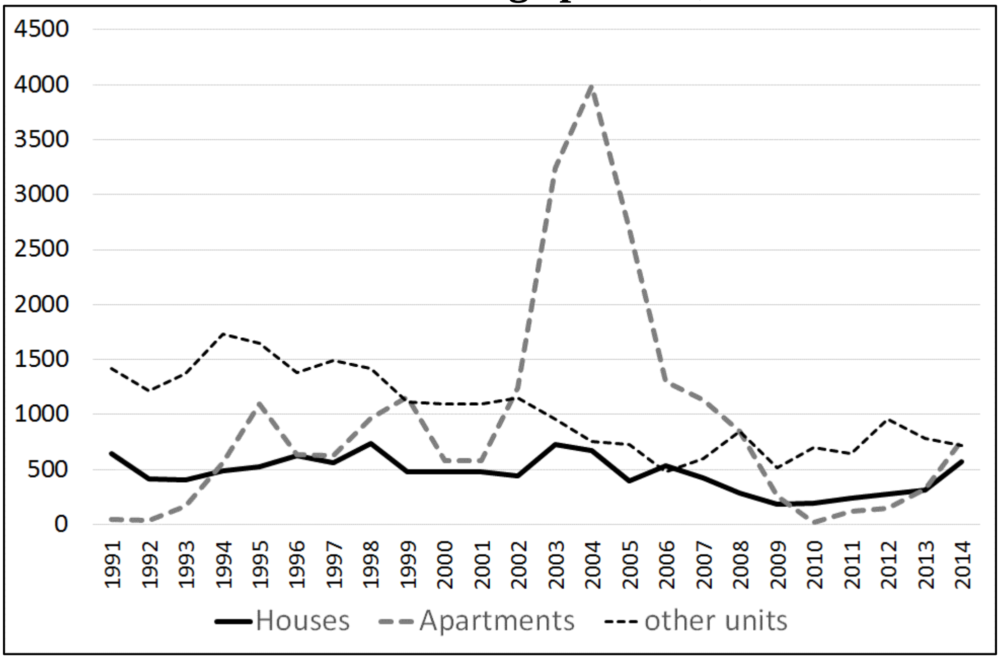
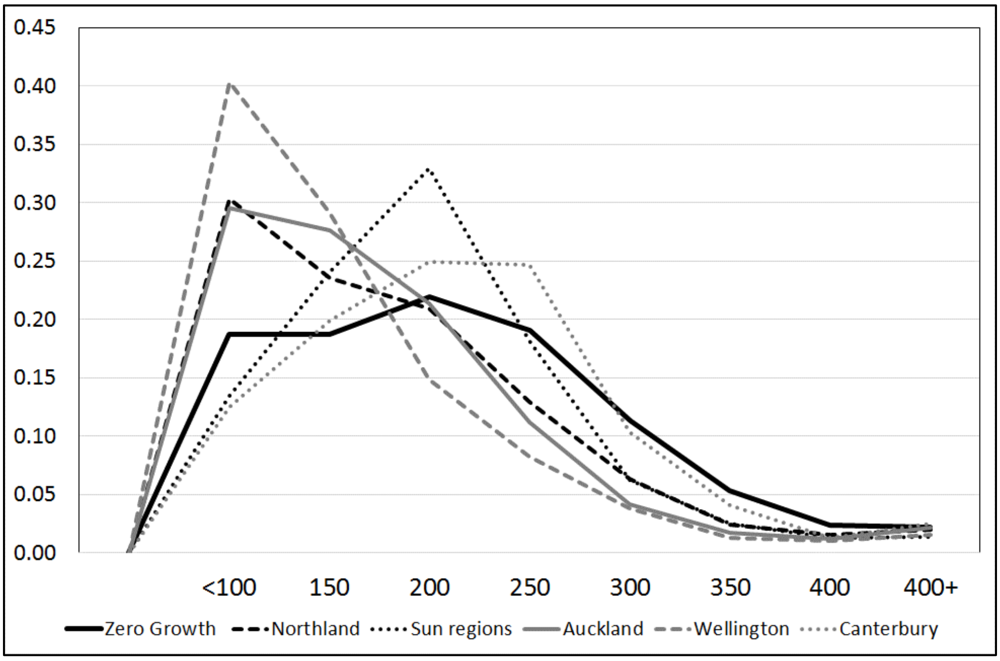
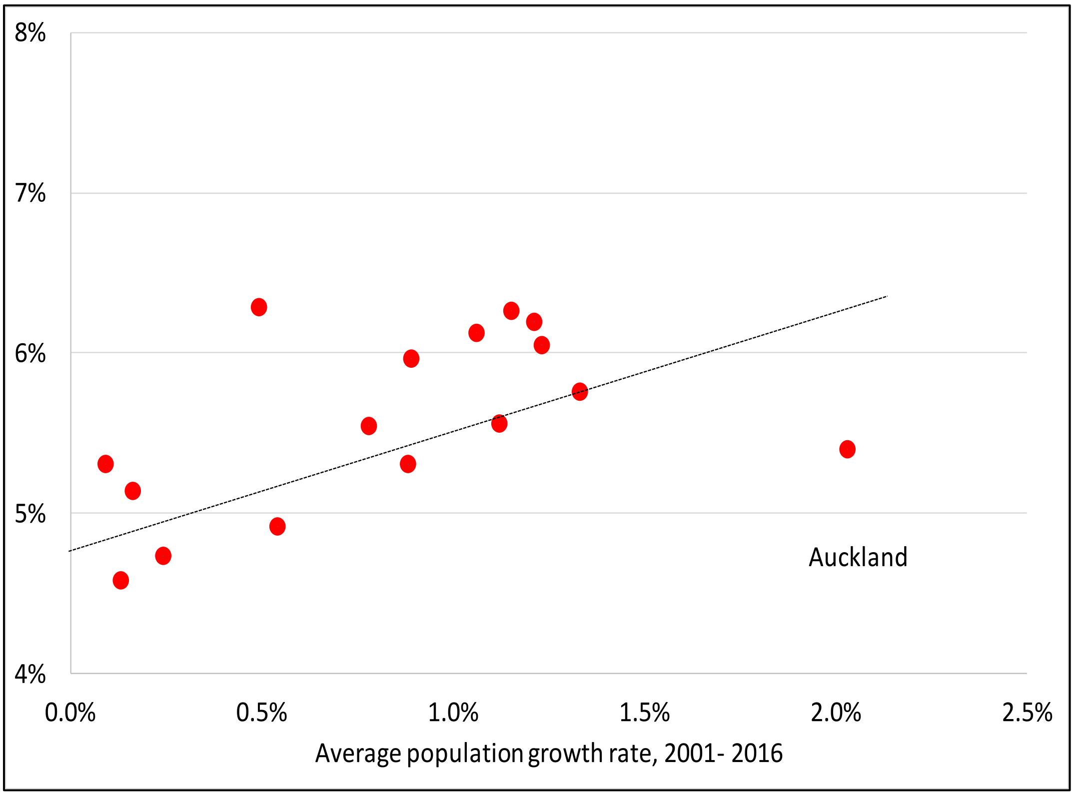


Figure 7
Marginal distribution of building permits by size
1997 – 2006



'Zero growth' regions are Gisborne, Wanganui-Manawatu, West Coast and Southland 'Sun regions' are Waikato, Bay of Plenty, Tasman, Nelson

Figure 8
Fraction of Builders in the workforce versus population growth by region, 2001 – 2016



Appendix. The relationship between age-specific population change and building activity.

This appendix contains the results of regressions estimating how the age structure of the population affects the amount of new construction. The data are described in Section 3.

The following equations are estimated:

$$BP_{it}^{5} = \alpha_0^5 + \alpha_1^5 region\ dummy_i + \alpha_2^5 time\ dummy_t + \alpha_3^5 Christchurch + \sum_{k=1}^{4} \beta_k^5 \Delta Popn_{it}^{k} + e_{it}^{5} \qquad \textbf{(A1)}$$

$$BP_{it}^{5} = \alpha_0^5 + \alpha_1^5 region\ dummy_i + \alpha_2^5 time\ dummy_t + \alpha_3^5 Christchurch + \gamma_0^5 \Delta Popn_{it}^{tot} + \gamma_k^5 \Delta Popn_{it}^{k} + e_{it}^{5} \qquad \textbf{(A2)}$$

where $\Delta Popn_{it}^{k}$ is the population change in age-group k in region *i* during period *t*, as a fraction of the initial total population of that region.

The dependent variable is either the number of building permits, the area of building permits, or the real value of building permits. The results are compared to regressions in which all the population variable coefficients are the same (rows 1.1, 2.1 and 3.1). The coefficient estimates have high standard errors due to the high degree of correlation between the different demographic variables.

The results indicate that building activity responds mainly to the change in the total population, not to the age-specific variables. When the four variables are incorporated into the regression together (equation A1), it is not possible to reject the hypothesis that all four coefficients are the same for any of the three building permit measures (regressions 1.2, 2.2 and 3.2 in table A1). When a single age-specific variable is incorporated into the regression (equation A2), it is not possible to reject the hypothesis that the coefficient is zero in all but two cases. The exceptions are regressions 2.4 and 3.4, in which the total size and value of building permits are regressed against the total population change and the fraction of the population that is aged 15-39. This variable leads to a marginal improvement in the statistical fit of the regressions. The large standard errors make it is difficult to provide a sensible interpretation to the estimated coefficients, however, as these suggest that building permit demand is highly responsive to the change in the number of 15 – 39 year olds in the population, and unresponsive to all other age groups. Note that if the point estimates were taken seriously, the estimated shortfall in Auckland's housing would be substantially larger than the estimates produced in the main part of the paper as Auckland has the largest increase of any city of the fraction of its population in the 15 – 39 age group.

Table A1: Regression coefficients between building permit measures and demographic variables

	Total population	**0-14**	**15- 39**	**40 – 64**	**65+**	**R2**	**F-test**
	Dependent Variable: building permits per capita						
1.1	0.229 (0.032)**					0.88	
1.2		0.215 (0.13)	0.311 (0.07)**	0.086 (0.10)	-0.011 (0.19)	0.89	0.78
1.3	0.217 (0.052)**	0.44 (0.15)				0.88	0.09
1.4	0.132 (0.08)		0.197 (0.147)			0.88	1.77
1.5	0.252 (0.045)**			-0.088 (0.12)		0.88	0.50
1.6	0.228 (0.032) **				-0.171 (0.167)	0.88	1.02
	Dependent Variable: square metres building permit per capita						
2.1	36.2 (5.9)**					0.89	
2.2		27.9 (21.9)	56.1 (12.8)**	6.4 (19.4)	-24.4 (33.9)	0.90	1.93
2.3	35.3 (10.2)**	3.7 (28.6)				0.89	0.02
2.4	12.9 (13.9)		47.7 (24.2)*			0.89	3.88*
2.5	40.0			-14.3		0.89	0.34

	(8.7) **			(24.4)			
2.6	35.9 (6.0)**				-46.3 (29.3)	0.89	2.46
	Dependent variable: real value of Building permits per capita (2016 values)						
3.1	54400 (11000)**					0.86	
3.2	40200 (38000)	97600 (25100) **	-13100 (31800)	-35100 (57400)		0.87	1.44
3.3	52100 (17600) **	9300 (47800)				0.86	0.04
3.4	7600 (25400) **		95800 (46100)*			0.87	4.32*
3.5	67500 (15700) **			-48800 (39700)		0.86	1.51
3.6	54100 (11100) **				-57000 (50500)	0.86	1.27