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PRODUCTIVITY COMMISSION
Te Kōmihana Whai Hua o Aotearoa

The effect of Auckland's Metropolitan Urban Limit on land prices

Research Note
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The New Zealand Productivity Commission: The Effect of Auckland's Metropolitan Urban Limit on Land Prices

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Information on the Productivity Commission can be found on www.productivity.govt.nz or by contacting +64 4 903 5150.

Abstract

This research note estimates the impact of Auckland’s Metropolitan Urban Limit (MUL) on land values in the greater Auckland region. Building on the work of Grimes and Liang (2009), it uses a quantile regression to assess the impact of the MUL on land prices by decile. This allows the impact of the MUL to be assessed in terms of both the central tendency (e.g. median) and the dispersion (e.g. lower or upper quartile). The results indicate that Auckland’s MUL has significantly increased land prices in general, but with a relatively larger impact on land prices in the lower part of the distribution.

Contents

1 Introduction

House prices in New Zealand escalated markedly over the 2000s, leading to significant falls in affordability (NZPC, 2012). Between 2001 and 2007, real house prices almost doubled, an average increase of approximately 12% per year. Over this period, the price premium for Auckland housing relative to the rest of the country increased, particularly at the lower end of the price distribution. This exacerbated housing affordability pressures in the city, which accounts for 31% of the quantity of New Zealand's housing stock and and 41% of the value. As such, Auckland is in many ways the epicentre of New Zealand's housing affordability problem.

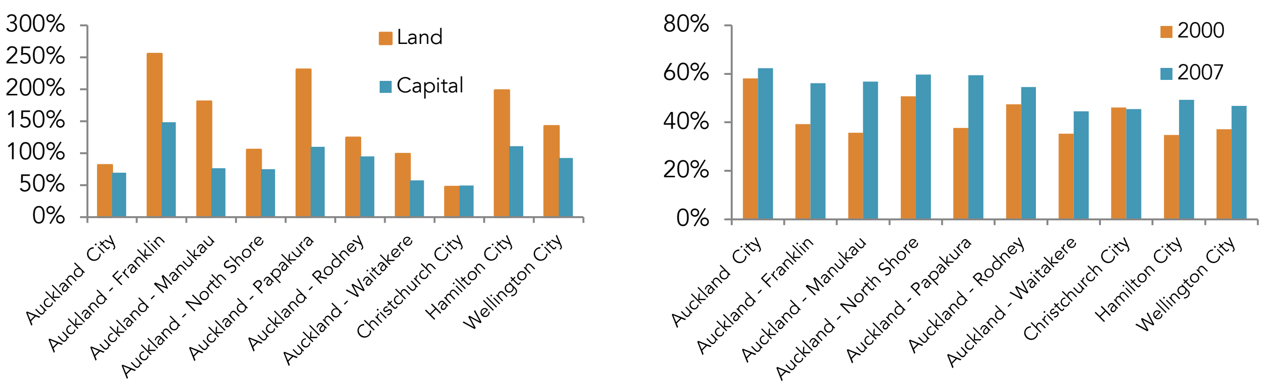
Another feature of New Zealand's housing market is that section prices have grown more quickly than house prices over the last twenty years, suggesting that land supply may have become less responsive to increases in housing demand (Figure 1a). Pressure on land prices has been particularly acute in Auckland and land now accounts for around 60% of the cost of an Auckland house, compared to 40% in the rest of the country (Figure 1b).

Auckland's Metropolitan Urban Limit (MUL) is a zoning restriction that defines "the boundary of the urban area with the rural part of the region" (Auckland Regional Growth Forum, 1999). Grimes and Liang (2009) find that the MUL has had a significant impact on land prices in the city, with the price of land just inside the MUL around 10 times higher than land just outside the MUL. In its Housing Affordability Inquiry published in April 2012, the New Zealand Productivity Commission used a similar methodology and found that the value of land just inside the MUL boundary is almost nine times greater than the value of land just outside the boundary (Figure 2).

These results suggest that Auckland's MUL is a binding constraint on land supply. Further, the magnitude of the land price differential across the MUL has increased since the late 1990s, suggesting that the MUL has become an increasing constraint as housing demand has intensified. These results are consistent with the international evidence of a strong positive relationship between restrictive land use policies and house prices (Gyouroko, 2009).

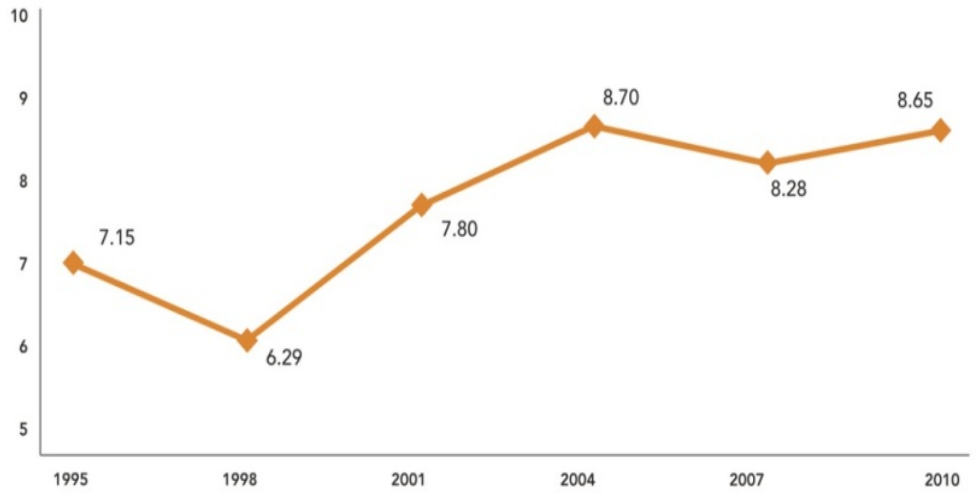
Figure 1 Residential land and house prices: Auckland vs. selected New Zealand cities

a. Real price change, 2001-2007 b. Land share of house prices



Source: QVNZ

Figure 2 The estimated impact of the Auckland MUL on residential land prices



Source: Housing affordability report from New Zealand Productivity Commission
Note: The price multiple of land 2km within the MUL to land 2km outside the MUL

This paper builds on these empirical results by investigating whether the impact of the MUL is uneven across the land price distribution. This approach follows from the finding in the Productivity Commission's inquiry into housing affordability of "missing rungs" on the housing ladder for those making the transition into home ownership, particularly in Auckland.

2 Method

This section outlines the regression model used to estimate the impact of Auckland's MUL on the distribution of land prices in the region. The model extends the work of Grimes and Liang (2009) by using a quantile regression focused on land prices by decile.[1]

Traditional regression analysis, such as ordinary least square, focuses on conditional means. As such, it summarises the relationship between the response variable and the predictor variables by describing the mean of the response for each fixed value of the predictors (Hao & Naiman, 2007). This conditional-mean framework cannot extend to non-central locations – such as lower and upper quartiles – and, as such, does not reflect potentially informative relationships in the response distribution.

Quantile regressions overcome this limitation and allow for a comprehensive analysis of the relationship over the distribution of response and predictor variables (Koenker & Bassett, 1978; Koenker, 2005). In addition, this technique makes no distributional assumptions about the error term in the model, allowing greater flexibility in modelling heterogeneous data.

In the quantile regression used in this paper, real median land prices ($ per hectare) are modelled at the meshblock level across the former seven Auckland territorial authorities – Rodney, North Shore, Waitakere, Auckland City, Manukau, Papakura and Franklin. This adds up to around 8,000 meshblocks each year.[2]

[1] A detailed description of this methodology can be found in Koenker, R. W. (2005). This approach uses the kernel estimate developed by Powell(1990) to correct for heteroscadasticity in the standard errors.

[2] Real median land prices are CPI-deflated land prices from QVNZ, and meshblocks are defined in 2006 Census.

Land prices are based on the land value portion of Quotable Value New Zealand (QVNZ) residential property valuations. The median land values at the meshblock level are weighted medians for two main types of properties – residential dwellings and lifestyle dwellings. These properties usually have detached or semi-detached dwellings on clearly defined sections and make up over 70% of the total number and value of dwellings in the Auckland region. For other dwelling types, land area is difficult to measure given there is no legally assigned portion to the land parcel, like a flat or apartment. As such, these dwellings are excluded from the analysis.

The estimated regression is given in equation (1).

$Q[Y|X,q] = X'\beta_q$ such that $prob[Y - X'\beta_q \leq 0|X] = q, 0 < q < 1$

Y and X are dependent and independent variables respectively. $Q[Y|X,q]$ is a function of the quantile regression with regard to specific quantile q.

$$\ln(RLV_i) = \theta_2 MUL_2 + \theta_3 MUL_3 + \theta_4 MUL_4 + \sum_{j=1}^{J} \beta_j NOD_j + \pi_1 URBAN + \rho_4 TA_4 + \rho_5 TA_5 + \rho_6 TA_6 + \rho_8 TA_8 + \rho_9 TA_9 + \rho_{10} TA_{10} + \pi_1 LON + \pi_2 LAT + \pi_3 LON^2 + \pi_4 LAT^2 + \pi_5 LON * LAT + \alpha + \varepsilon_i \quad (1)$$

Where,

Ln(RLV) is the log of real median land value per hectare in meshblock i in 1995 prices.

MUL is the MUL dummies. MUL_2, MUL_3 and MUL_4 are assigned to meshblocks 2km inside the MUL, 2km outside the MUL and more than 2km outside the MUL respectively. MUL_1, which is assigned to meshblocks more than 2km inside the MUL, is set as a baseline.

TA is TA dummies. TA_4, TA_5, TA_6, TA_8, TA_9 and TA_{10} represent Rodney, North Shore, Waikakere, Manukau, Papakura and Franklin respectively. Auckland city, TA_7, is set as a baseline.

URBAN is an urban dummy, as defined by Census urban and rural classification in 2006[3].

NOD is a local centric node dummy variable. NOD=1 when a meshblock is no more than 5km away from the centric node. Otherwise, NOD=0.

LAT and LON represent latitudes and longitudes of meshblock centroids. They are included in the regression in linear, quadratic and interaction terms.

α is the intercept

ε is residuals, which are assumed to be independently distributed.

This regression includes a range of location factors that capture large-scale variations in land values associated with geographic location. These location factors are territorial authority (TA) dummies, urban area dummies, local centric nodes and latitude-longitude. TA dummies consist of Rodney, North Shore, Waitakere, Manukau, Papakura and Franklin. Urban area dummies were derived from rural and urban profiles from the 2006 Census (Statistics New Zealand). Rural areas were defined as rural areas with high, moderate or low urban influence[4]. Recognising that Auckland is polycentric, the local centric nodes reflect business centres (e.g. Parnell West and Meadowbank North in the central Auckland zone) that have high economic activity in their local

[3] Collinearity between Urban and MUL dummies may contribute unstable or biased coefficient estimates. To test for this bias, a bootstrap estimation is run 200 times and coefficients estimates compared with and without Urban dummy variables. The results suggest that differences in coefficient estimates given the inclusion of Urban dummies are statistically insignificant at the 95% level of confidence.

[4] Census urban/rural profile can be found http://www.stats.govt.nz/surveys_and_methods/methods/classifications-and-standards/urban-rural-profile-experimental-class-categories.aspx.

communities.[5] Quadratic terms of latitude and longitude, including the interaction term, were used to capture the distributional effect of land values associated with location[6].

The key variables of interest in the model are the MUL dummy variables. The dummy variables were constructed on the basis of meshblock distance from the MUL boundary. Specifically, each meshblock is assigned into one of four categories depending on its distance to the MUL. The categories are: greater than 2km inside the MUL (MUL_1), 2km within the MUL (MUL_2), 2km outside the MUL (MUL_3), and greater than 2km outside the MUL (MUL_4). If a meshblock is dissected by the MUL, it is randomly assigned to either just inside or outside the MUL using a uniform distribution[7]. This study uses the 2009 MUL boundary and assumes that it has remained constant over time. [8] Although this is not strictly accurate, changes in the MUL have been relatively minor over the last 15 years. Maps of the MUL dummy variables are given in appendix 1.

3 Data

Historic house price data from 1995 to 2010 was sourced from QVNZ. This data provides capital, land and improvement values as well as land area and type. These values are only updated when revaluations are carried out, which normally occurs in three-year cycles that can vary by territorial authority.

Interpolation was used to estimate land prices between these valuation dates. This interpolation was made conditional on house sales data as an indicator of price movement between revaluation years. This sales data contains sale prices on houses sold each year and records the median sale price at TA level. As such, the interpolation is based on two main assumptions:

1. land prices are strictly correlated with house sale prices, and
2. land price movements in meshblocks within the same territorial authority are identical.

The first assumption matches movement of land prices with house sales prices while the second is necessary given that house sales price at the meshblock level are unavailable.

This method of interpolation is depicted in equation (2):

$$L_{t+i} = L_t + (\,L_{t+c} - L_t\,)\left(\frac{S_{t+i}-S_t}{S_{t+c}-S_t}\right) \qquad (2)$$

L and *S* are land and house sales price indexes respectively. Subscripts t and c are the first year of valuation and the length of cycle (e.g. 2, 3 or 4 years). Subscript i is the time period of interpolation, which falls between t and t + c.

Using this equation, interpolated land prices (L_{t+i}) are calculated in two parts – the observed land price at the beginning of the valuation year (L_t) plus the change in house value between valuation years. This distributes the observed increment across revaluation cycles ($L_{t+c} - L_t$) by the

[5] Selection of local centric nodes are given in Grimes and Liang 2009, except Piha, Henderson and Omaha.

[6] The quadratic terms of latitude and longitude is recommended in Pace and Gilley 1997

[7] The MUL dissects 162 meshblocks, which is roughly 2% of the total meshblocks in the Auckland region.

[8] Islands in the Auckland region are excluded.

proportion of incremental change in the house sale price index over the same period$\left(\frac{S_{t+i}-S_t}{S_{t+c}-S_t}\right)$. Real land prices are calculated on the basis of 1995 constant prices using the CPI.

4 Results

Summary statistics

Tables 1 to 3 provide summary statistics on real land prices by quantiles across the MUL groups defined above. For easy reading, these statistics are reported for every third year. Key points to note are:

1) Land prices decline from MUL_1 to MUL_4, that is, from well inside the MUL to well outside (more than 2km) the MUL. This most likely reflects the impact of distance to the CBD on Auckland land prices.

2) The MUL boundary is associated with relatively large price changes for lower-quartile and median priced land. For instance, over the period 1995-2010, land in the lower-quartile of the price distribution within 2km inside the MUL (MUL_2) was eight time more expensive than lower-quartile land within 2km outside the MUL (MUL_3). The equivalent figure for median priced land is nearly five times more expensive. For land priced in the upper-quartile, the price differential across the MUL is around two (Figure 3).

3) For lower-quartile priced land, real price increases have been largest for land inside the MUL, particularly land within 2km inside the MUL (MUL_2). In contrast, lower quartile land outside the MUL has experienced smaller price increases over the sample period.

4) For upper-quartile priced land, real price increases have been largest for land located more than 2km outside the MUL (MUL_4). This may reflect increased demand for coastal land and lifestyle blocks.

In sum, these summary statistics suggest that the impact of the MUL on land prices may be concentrated on land located just within the boundary and in the lower part of the price distribution.

Table 1 Real land price per hectare (1995 prices) by distance to the MUL - lower-quartile

Lower-Quartile	1995	1998	2001	2004	2007	2010	Count	% change 95 - 10
MUL1	612,006	599,128	867,115	1,193,720	2,164,494	2,531,960	5,416	314%
MUL2	405,205	375,952	462,086	765,334	1,379,914	1,726,659	2,294	326%
MUL3	47,766	58,149	72,782	89,907	144,313	184,590	2,22	286%
MUL4	24,507	30,712	38,161	51,623	85,604	98,995	879	304%

Source: QVNZ

Table 2 Real land price per hectare (1995 prices) by distance to the MUL - median

Median	1995	1998	2001	2004	2007	2010	Count	% change 95-10
MUL1	956,702	1,039,128	1,461,094	2,035,915	3,470,675	3,534,351	5,416	269%
MUL2	492,288	476,459	637,069	965,015	1,868,390	2,077,143	2,294	322%
MUL3	109,866	120,873	169,622	214,852	370,284	380,311	222	246%
MUL4	52,182	65,504	80,624	109,121	197,555	215,803	879	314%

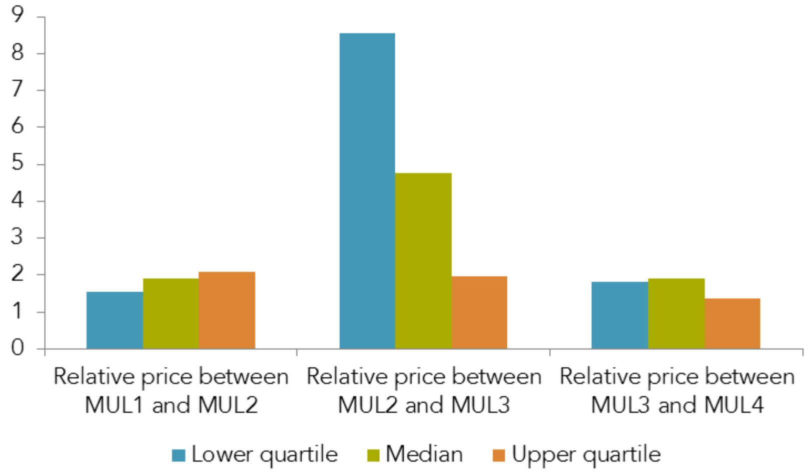
Source: QVNZ

Table 3 Real land price per hectare (1995 prices) by distance to the MUL - upper-quartile

Upper-Quartile	1995	1998	2001	2004	2007	2010	Count	% change 95-10
MUL1	1,520,958	1,815,876	2,491,920	3,615,172	5,511,004	5,392,102	5,416	255%
MUL2	689,022	818,923	1,060,365	1,485,820	2,836,567	2,896,644	2,294	320%
MUL3	386,102	412,105	578,933	780,399	1,161,163	1,649,450	222	327%
MUL4	234,466	270,333	326,978	563,465	1,064,863	1,183,199	879	405%

Source: QVNZ

Figure 3 Relative price difference by distance to the MUL, 1995-2010



Note: MUL_1 – land well inside MUL
MUL_2 – land just inside MUL (within 2km)
MUL_3 – land just outside MUL (within 2km)
MUL_4 – land 2km outside MUL

Regression results

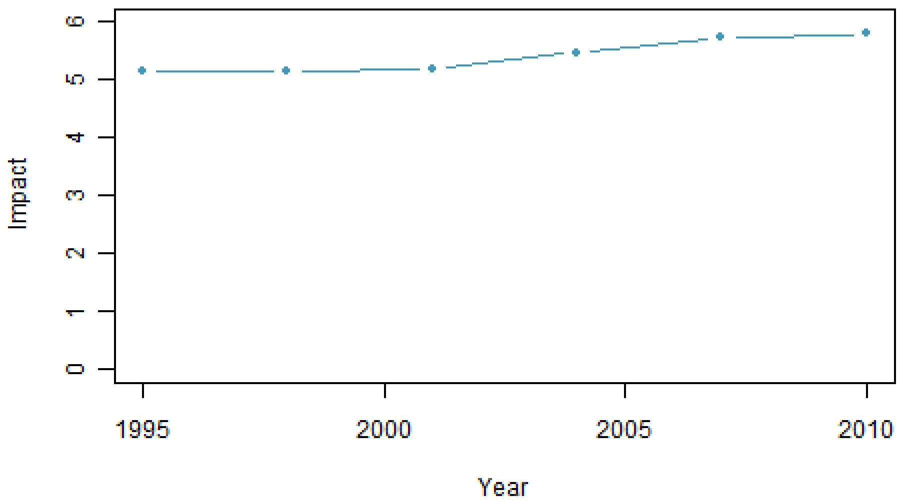
This section outlines the results of estimating equation 1 – using both OLS and a quantile regression – to assess the effects of the MUL boundary on real land prices over the period 1995-2010. The estimation results, which are outlined in detail in appendix C, reveal that spatial correlation in land prices is statistically significant. This has the potential to either bias coefficient estimates or make them inefficient (Anselin, 1988). To test for this, a bootstrapping exercise is conducted on both the OLS and quantile regressions. The results of this exercise suggest that coefficient estimates remain unbiased given significant spatial correlation, but that their standard errors are somewhat larger than would otherwise be the case (see appendix C for more details).

The impact of the MUL is measured as the difference between the prices of land within 2km inside the MUL relative to land within 2km outside the MUL, once the other drivers of land prices are accounted for by the regression. That is, the difference between the coefficients on MUL_2 and MUL_3.[9]

For mean and median priced land, both OLS and quantile regressions estimate a similar price differential across the MUL of around five to six times (Figures 4 and 5). However, the impact of the MUL is estimated to be uneven, with a disproportionately large impact on lower decile land. Specifically, the price differential associated with the MUL for land in the lowest decile of the price distribution is around 10, compared to a price differential of 5 for land at the median price point and 1.3 for land in the highest decile (Figure 5). These regression results are broadly consistent with the summary statistics reported above.

Over the sample period, the impact of the MUL on land priced at the lowest decile and median is estimated to have increased. In 1995, the impact of the MUL on the lowest decile and median land was 8.1 and 4.3 respectively. By 2010, this had increased somewhat to 9.7 and 5.6 respectively (up 20% and 30%). Conversely, the impact of the MUL on the land valued at the highest decile remained relatively flat, at just 1.3. This suggests that much of the binding constraint of the MUL falls on land in the lower part of the price distribution. Consequently, price gaps between less and more expensive land have widened over this period (Figure 6).

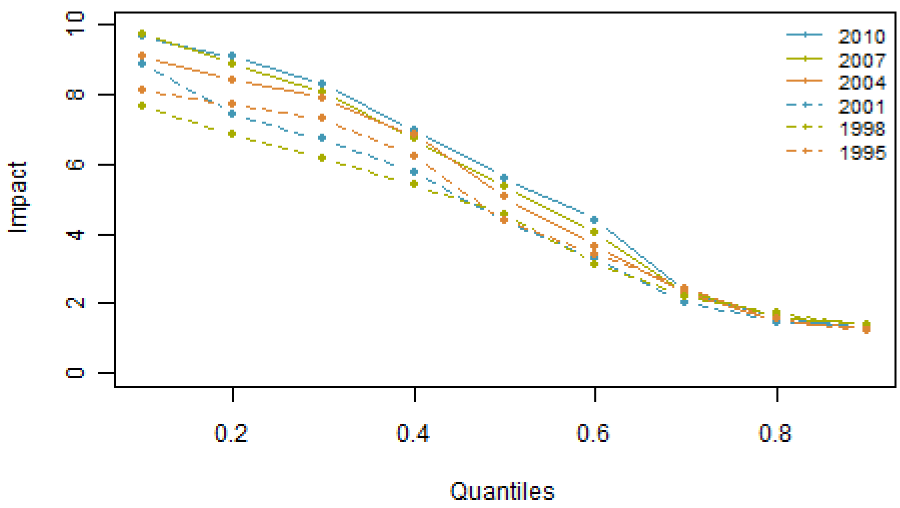
Figure 4 Relative price difference between MUL2 and MUL3 (OLS regression)



Source: QVNZ; Author's calculations

[9] This difference is calculated as $\exp(\theta_2 - \theta_3)$ given that the dependent variable is in logs.

Figure 5 Relative price differences between MUL2 and MUL3 (quantile regressions)

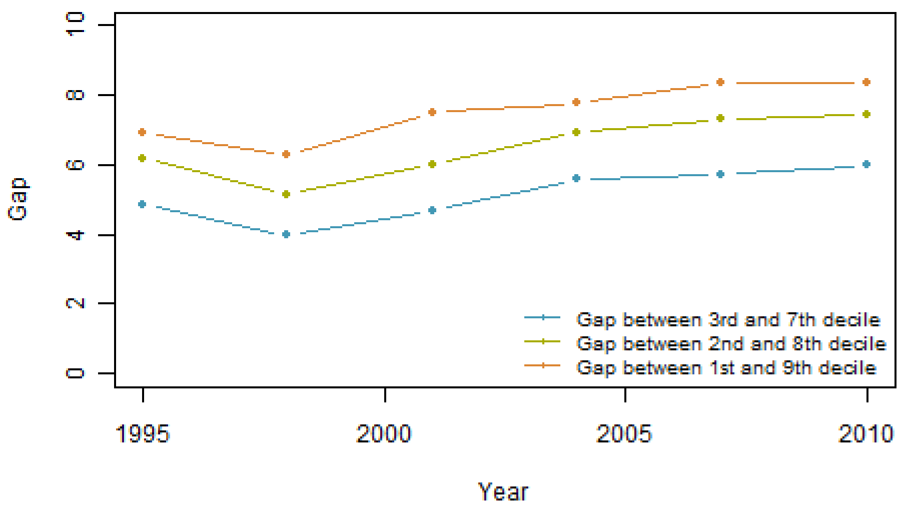


Source: QVNZ; Author's calculations

Notes:

1. Impact is calculated as the difference between the value of land within 2km inside the MUL relative to land within 2km outside the MUL.
2. Impact is estimated by decile and time.

Figure 6 Growth on inter-quantile gaps (quantile regression)



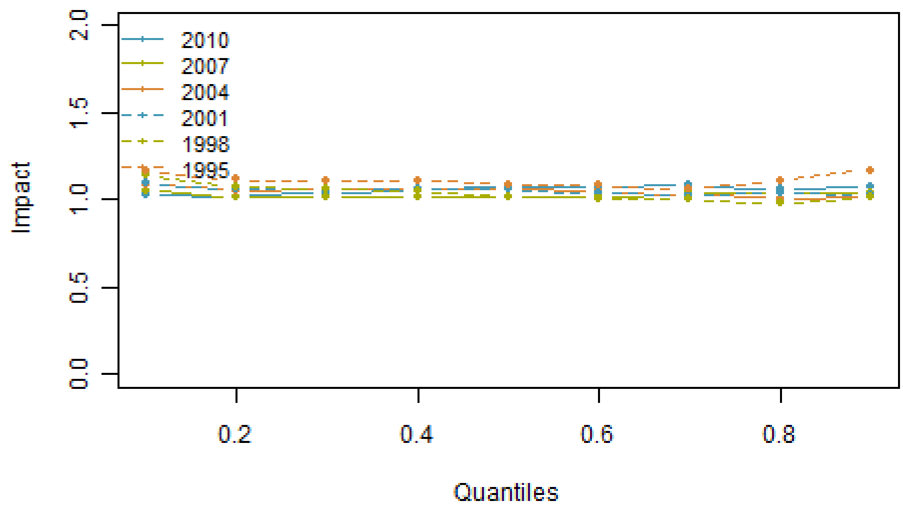
Source: QVNZ; Author's calculations

Notes:

1. Gap between 1st and 9th decile is calculated as the difference of impact between 1st and 9th deciles
2. Gap between 2nd and 8th is calculated as the difference of impact between 2nd and 8th deciles
3. Gap between 3rd and 7th decile is calculated as the difference of impact between 3rd and 7th deciles

Within urban Auckland, the relative price differential for land 2km inside the MUL and land more than 2km inside the MUL is estimated to be around 1, indicating uniformity once the impact of distance to the CBD and other factors are accounted for by the regression (Figures 7 and 8). For land outside the MUL, there is some evidence of a price differential for land within 2km outside the MUL and land further away for relatively more expensive land. But this differential is much smaller than for land on either side of the MUL. These results indicate that the MUL does not significantly influence land price pressures in urban or rural areas but instead has a significant impact on the price of urban land relative to rural land.[10]

Figure 7 Relative price differences between MUL1 and MUL2 (quantile regression)

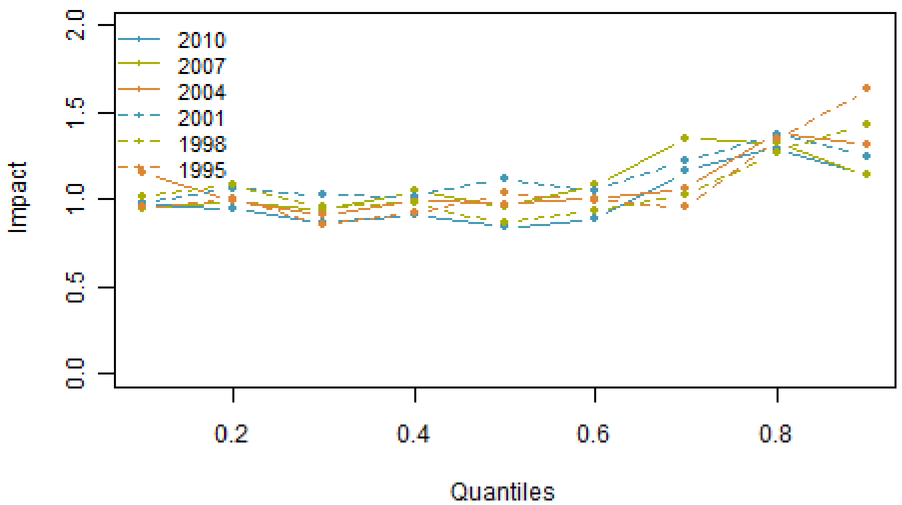


Source: QVNZ; Author's calculations

Notes:

1. Impact is calculated as the difference between the value of land within 2km outside the MUL relative to land more than 2km outside the MUL.
2. Impact is estimated by decile and time.

Figure 8 Relative price difference between MUL3 and MUL4 (quantile regression)



Source: QVNZ; Author's calculations

Notes:

1. Impact is calculated as the difference between the value of land more than 2km inside the MUL relative to land within 2km inside the MUL.
2. Impact is estimated by decile and time.

[10] Urban areas are contained in MUL_1 and MUL_2, and rural areas are contained MUL_3 and MUL_4.

5 Conclusion

The empirical results presented in this paper indicate that the containment of Auckland region via the MUL results in upward pressure on residential land prices within the urban areas. This impact is found to be uneven with a much larger impact on land at the lower end of the price distribution. This suggests that the impact of the MUL on housing affordability is most pronounced for those at the lower end of the housing market. One reason for this is that lower priced land is more often found further out on the fringes of cities. Table 4 shows 12% of meshblocks are located outside the MUL boundaries. Of those, 86% of them are priced at bottom quartile price range. When an artificial "fence" delineates residential land from non-residential land on the urban fringe, it limits the supply of lower priced land, with a resulting impact on prices at the lower end of the housing market. And, when the supply of land on the urban periphery is restricted, the price of available residential land rises and new builds tend to be larger and more expensive houses. This suggests that the MUL has become increasingly binding at this end of the market as housing demand has intensified in the Auckland region.

Table 4 Frequency table of meshblocks in lower-quartile price and MUL in 2010

	Inside the MUL	Outside the MUL	Total
Above lower-quartile land price	6449	155	6604
Below lower-quartile land price	1261	941	2202
Total	7710	1096	8806

Source: QVNZ

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Appendix A Auckland's MUL Regions

MUL regions in the Auckland region

Please note: This study uses the 2009 MUL boundary and MUL regions are identified by QVNZ. Legend 1, 2, 3 and 4 in each graph represent MUL_1, MUL_2, MUL_3 and MUL_4.

Figure A.1 MUL regions in Rodney and North Shore Districts

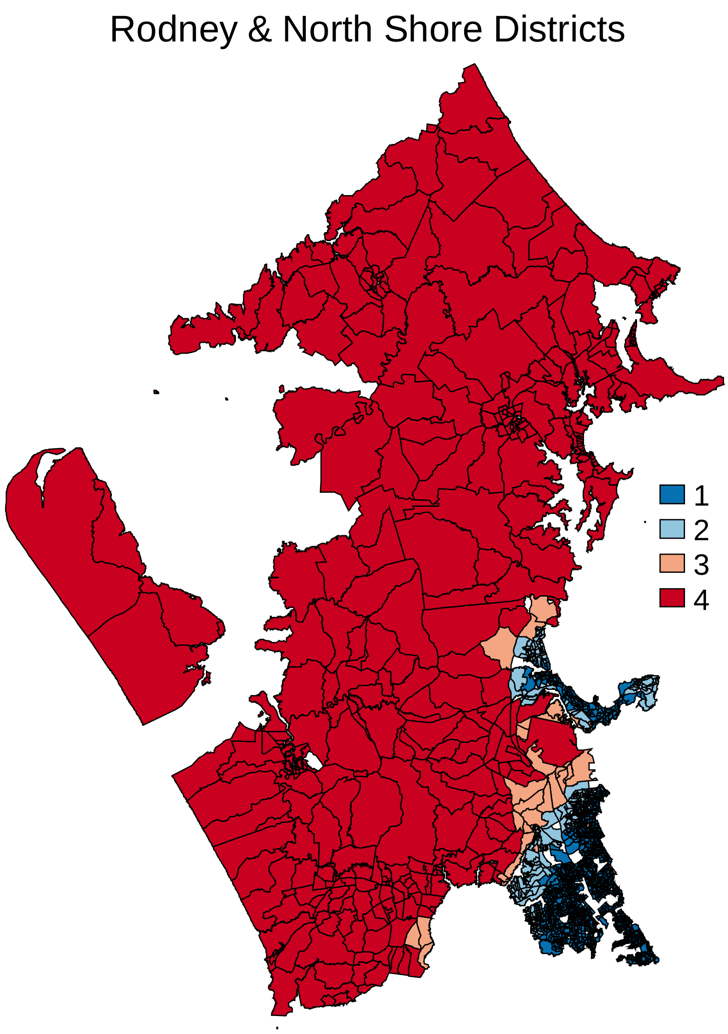


Figure A.2 MUL regions in Auckland City and Waitakere Districts

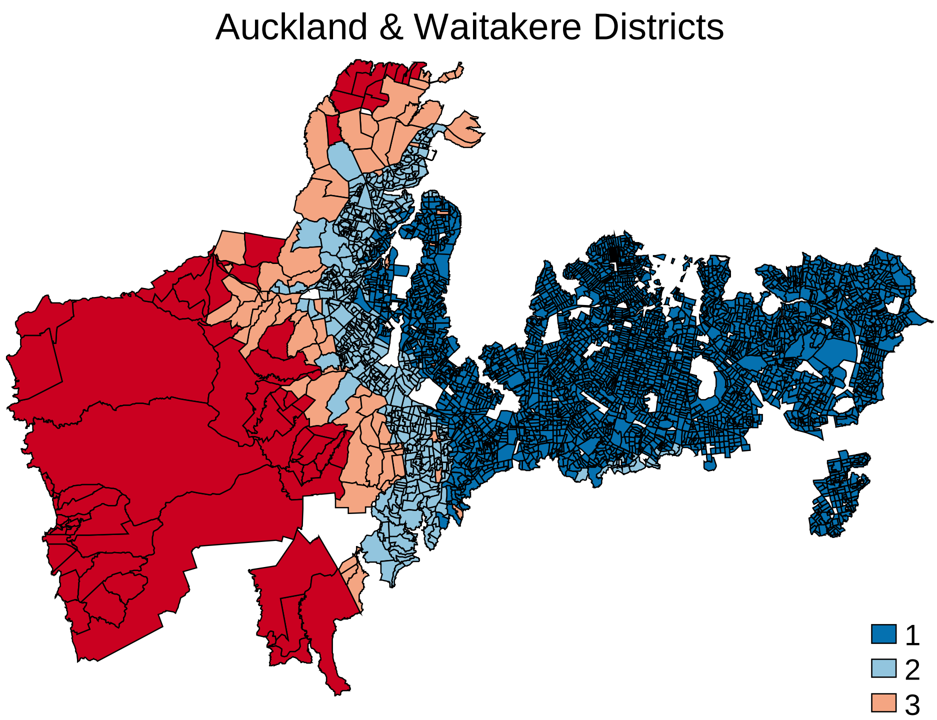
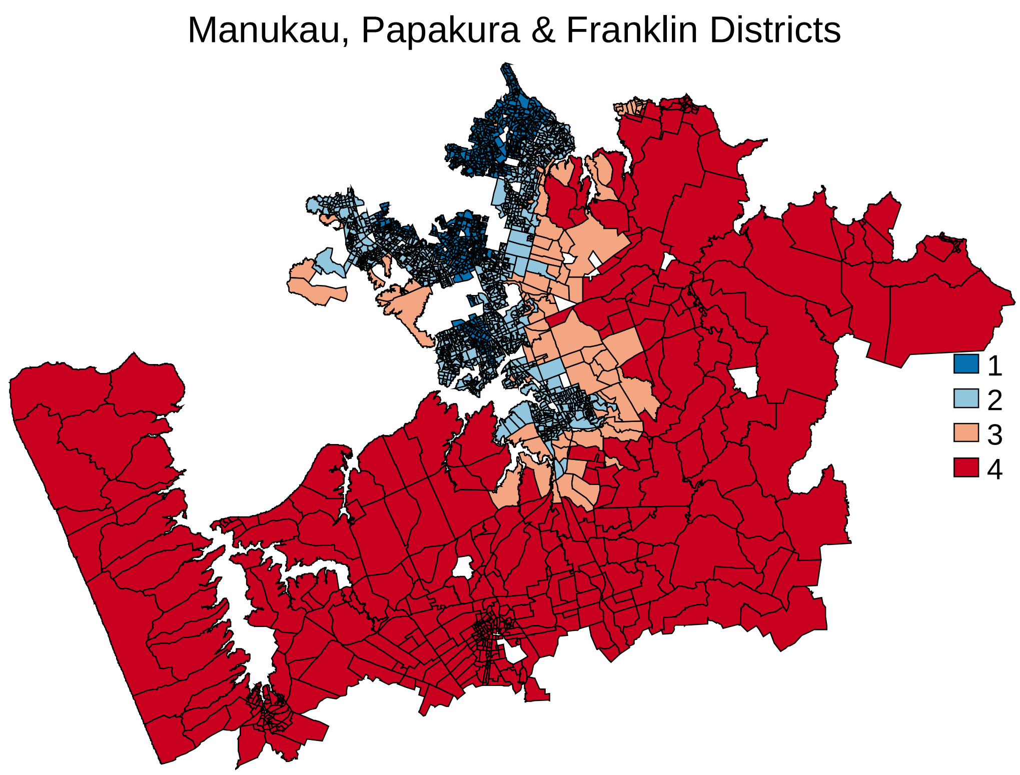


Figure A.3 MUL regions in Manukau, Papakura and Franklin Districts



Appendix B Coefficient estimates for selected right-hand side variables from the quantile regression

Please note, tau represent deciles
*** p<0.01, **p<0.05, * p<0.1

	1995									1998								
	tau= 0.1	tau= 0.2	tau= 0.3	tau= 0.4	tau= 0.5	tau= 0.6	tau= 0.7	tau= 0.8	tau= 0.9	tau= 0.1	tau= 0.2	tau= 0.3	tau= 0.4	tau= 0.5	tau= 0.6	tau= 0.7	tau= 0.8	tau= 0.9
tla1	-0.79***	-0.77***	-0.83***	-0.84***	-0.87***	-0.84***	-0.92***	-1.01***	-0.98***	-0.43***	-0.45***	-0.53***	-0.56***	-0.64***	-0.75***	-0.89***	-1.05***	-1.24***
tla2	0.04	0.03	0.01	0.00	-0.03	-0.03	-0.05***	-0.04	-0.02	0.23**	0.19***	0.12**	0.08	0.02	-0.04	-0.12*	-0.20**	-0.29**
tla3	-0.61***	-0.60***	-0.59***	-0.63***	-0.68***	-0.71***	-0.72***	-0.81***	-0.96***	-0.49***	-0.50***	-0.54***	-0.58***	-0.62***	-0.66***	-0.76***	-0.87***	-1.05***
tla5	-0.03***	-0.12**	-0.15**	-0.20**	-0.30***	-0.39***	-0.52***	-0.61***	-0.70***	-0.10*	-0.22***	-0.24***	-0.32***	-0.46***	-0.52***	-0.69***	-0.90***	-1.13***
tla6	-0.23***	-0.45***	-0.50***	-0.51***	-0.52***	-0.45***	-0.56***	-0.54***	-0.57***	-0.30***	-0.61***	-0.68***	-0.52***	-0.74***	-0.69***	-0.82***	-0.97***	-1.23***
tla7	-0.10**	-0.12**	-0.16**	-0.13**	-0.24***	-0.26***	-0.52***	-0.48***	-0.44***	0.07	-0.06	0.05	-0.03	-0.20**	-0.23***	-0.53***	-0.57***	-0.90***
MUL2	-0.15*	-0.11*	-0.10*	-0.10*	-0.09	-0.08	-0.06	-0.10	-0.16*	-0.14*	-0.07	-0.06	-0.04	-0.02	-0.01	0.00	0.02	-0.01
MUL3	-2.25***	-2.15***	-2.09***	-1.93***	-1.57***	-1.30***	-0.95***	-0.54***	-0.37***	-2.18***	-2.00***	-1.88***	-1.73***	-1.54***	-1.15***	-0.79***	-0.52***	-0.35***
MUL4	-2.20***	-2.16***	-1.93***	-1.85***	-1.60***	-1.30***	-0.91***	-0.83***	-0.86***	-2.19***	-2.08***	-1.84***	-1.71***	-1.39***	-1.08***	-0.81***	-0.76***	-0.72***

	2001									2004								
	tau= 0.1	tau= 0.2	tau= 0.3	tau= 0.4	tau= 0.5	tau= 0.6	tau= 0.7	tau= 0.8	tau= 0.9	tau= 0.1	tau= 0.2	tau= 0.3	tau= 0.4	tau= 0.5	tau= 0.6	tau= 0.7	tau= 0.8	tau= 0.9
tla1	-0.87***	-0.84***	-0.89***	-0.88***	-0.92***	-0.98***	-1.07***	-1.19***	-1.22***	-0.97***	-1.11***	-1.15***	-1.18***	-1.25***	-1.34***	-1.44***	-1.61***	-1.61***
tla2	-0.42***	-0.47***	-0.48***	-0.47***	-0.50***	-0.49***	-0.53***	-0.56***	-0.59***	-0.47***	-0.53***	-0.56***	-0.57***	-0.61***	-0.66***	-0.68***	-0.73***	-0.73***
tla3	-0.88***	-0.84***	-0.84***	-0.85***	-0.90***	-0.91***	-0.95***	-1.02***	-1.15***	-0.84***	-0.83***	-0.86***	-0.93***	-1.01***	-1.10***	-1.17***	-1.29***	-1.39***
tla5	-0.81***	-0.84***	-0.79***	-0.81***	-0.83***	-0.92***	-0.99***	-1.06***	-1.07***	-0.52***	-0.56***	-0.56***	-0.64***	-0.69***	-0.74***	-0.81***	-0.93***	-1.05***
tla6	-0.68***	-0.75***	-0.76***	-0.75***	-0.62***	-0.72***	-0.67***	-0.64***	-0.69***	-0.62***	-0.80***	-0.73***	-0.80***	-0.82***	-0.85***	-0.81***	-0.83***	-0.93***
tla7	-0.37***	-0.30***	-0.25***	-0.19**	-0.33***	-0.50***	-0.56***	-0.69***	-0.76***	-0.03	-0.22***	-0.12*	-0.11*	-0.19**	-0.12*	-0.32***	-0.47***	-0.52***
MUL2	-0.09	-0.06	-0.06	-0.05	-0.06	-0.04	-0.03	-0.03	-0.03	-0.09	-0.05	-0.06	-0.06	-0.06	-0.05	-0.03	-0.01	-0.02
MUL3	-2.28***	-2.07***	-1.97***	-1.81***	-1.53***	-1.22***	-0.74***	-0.40***	-0.35***	-2.29***	-2.18***	-2.12***	-1.98***	-1.68***	-1.34***	-0.86***	-0.41***	-0.29***
MUL4	-2.26***	-2.13***	-1.99***	-1.83***	-1.64***	-1.28***	-0.94***	-0.72***	-0.57***	-2.44***	-2.17***	-2.03***	-1.97***	-1.66***	-1.34***	-0.92***	-0.73***	-0.56***

	2007									2010								
	tau= 0.1	tau= 0.2	tau= 0.3	tau= 0.4	tau= 0.5	tau= 0.6	tau= 0.7	tau= 0.8	tau= 0.9	tau= 0.1	tau= 0.2	tau= 0.3	tau= 0.4	tau= 0.5	tau= 0.6	tau= 0.7	tau= 0.8	tau= 0.9
tla1	-0.98***	-1.09***	-1.12***	-1.12***	-1.13***	-1.25***	-1.29***	-1.34***	-1.46***	-0.74***	-0.78***	-0.79***	-0.77***	-0.83***	-0.88***	-0.90***	-1.03***	-1.20***
tla2	-0.43***	-0.44***	-0.46***	-0.44***	-0.44***	-0.49***	-0.49***	-0.48***	-0.50***	-0.39***	-0.39***	-0.37***	-0.37***	-0.40***	-0.41***	-0.42***	-0.46***	-0.51***
tla3	-1.13***	-1.14***	-1.14***	-1.14***	-1.17***	-1.26***	-1.31***	-1.40***	-1.59***	-0.45***	-0.43***	-0.40***	-0.46***	-0.51***	-0.56***	-0.61***	-0.69***	-0.83***
tla5	-0.34***	-0.34***	-0.32***	-0.36***	-0.38***	-0.42***	-0.44***	-0.51***	-0.54***	-0.37***	-0.36***	-0.34***	-0.37***	-0.39***	-0.41***	-0.43***	-0.49***	-0.54***
tla6	-0.38***	-0.45***	-0.38***	-0.41***	-0.48***	-0.47***	-0.46***	-0.53***	-0.52***	-0.68***	-0.73***	-0.66***	-0.67***	-0.66***	-0.67***	-0.65***	-0.68***	-0.71***
tla7	0.05	0.05	0.16**	0.20***	0.10*	0.28***	0.11**	-0.15**	-0.22***	-0.33***	-0.25***	-0.14**	-0.06	-0.03	0.00	-0.05	-0.12**	-0.33***
MUL2	-0.05	-0.01	-0.02	-0.01	-0.02	-0.01***	-0.03	-0.04	-0.04	-0.03	-0.02	-0.04	-0.06	-0.07	-0.07	-0.08	-0.06	-0.08
MUL3	-2.33***	-2.20***	-2.10***	-1.92***	-1.69***	-1.41***	-0.88***	-0.51***	-0.36***	-2.30***	-2.23***	-2.15***	-2.00***	-1.80***	-1.55***	-0.92***	-0.55***	-0.34***
MUL4	-2.27***	-2.19***	-2.04***	-1.97***	-1.65***	-1.49***	-1.18***	-0.79***	-0.49***	-2.27***	-2.17***	-2.01***	-1.90***	-1.62***	-1.43***	-1.07***	-0.80***	-0.47***

Appendix C Bootstrap study on the effects of spatial correlation on ordinary least square and quantile regressions

This bootstrap study evaluates whether the omission of terms to capture spatial correlation in OLS and quantile regressions can cause biased results.

According to LeSage and Pace (2009), omitted variables can easily arise in spatial modelling given that unobservable factors such as location amenities, highway accessibility or neighbourhood prestige may exert an influence on the dependent variable. It is unlikely that explanatory variables are readily available to capture these types of latent influences. If this is the case, regressions may return either bias or inefficient estimates of coefficients on explanatory variables (Anselin, 1988).

To determine the impact that spatial correlation may have on OLS and quantile regression estimates, a non-parametric bootstrapping technique based on Efron (1981) is used to evaluate the impact of spatial correlation on the stability of coefficient estimates. A bootstrapping approach is necessary given that the extent of spatial correlation cannot be calculated on the entire data set. Also, the theoretical distribution of coefficients is unknown in traditional regression analysis, while bootstrapping allows the properties of distribution to be assessed.

This evaluation was conducted using the following procedure:

(1) Measures of spatial correlation

- a) randomly draw a 20% sample (without replacement) from the entire dataset
- b) under this sample, run OLS and derive the residuals
- c) estimate spatial correlation using Moran's I test on the residuals (Moran, 1950; Cliff & Ord, 1981). Moran's I test statistics are based on the k-nearest neighbours. In practise, this means that each meshblock has to match exactly with the 20 physically closest meshblocks. Here k is set to 10 and 20.

(2) Stability of coefficient estimates

- a) For OLS
  - i. randomly draw a 20% sample (without replacement) from the entire dataset
  - ii. under this sample, run OLS and derive the coefficient estimates
  - iii. compute the distributions of coefficient estimates and correlations of coefficient estimates and spatial correlation from (1)
- b) For quantile regression
  - i. randomly draw a 20% sample (without replacement) from the entire dataset
  - ii. under this sample, run quantile regressions and derive coefficient estimates
  - iii. compute empirical distributions of coefficient estimates

This bootstrapping was applied to 2010 data and run 200 times.

Results: (1) measures of spatial correlation

The results from this test suggest that spatial correlation is statistically significant in the dataset. But the strength of the correlation is relatively weak, at no more than 0.15 (Figure A3.1). This suggests that the impact of the relatively weak spatial correlations on coefficient estimates may be limited.

Results: (2) stability of coefficient estimates

This test is run on the coefficients on the key variables that are used to evaluate the MUL boundary effect – MUL2 and MUL3. For OLS, the distributions both these coefficients are normal (Figure A3.2) and the coefficients are uncorrelated with spatial correlations (Figure A3.3). Similarly, a bootstrapping exercise on the quantile regression shows that the distributions on MUL coefficients over deciles are stable and symmetric (Figure A3.4).These results gives some confidences that coefficient estimates are stable and are not influenced by spatial correlation. Hence, OLS and quantile regression estimates are unlikely to be biased but are inefficient to some degree.

Figure C.1 Density distribution of spatial correlation

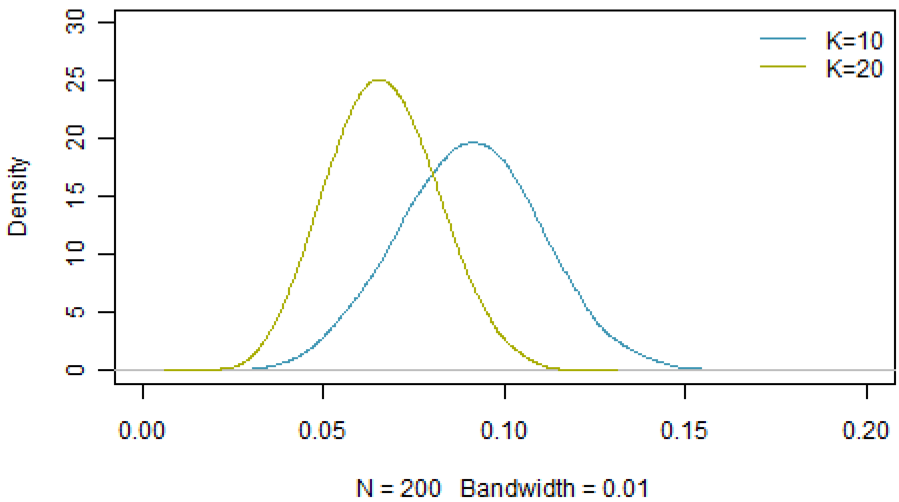


Figure C.2 Density distributions of MUL2 and MUL3 coefficients

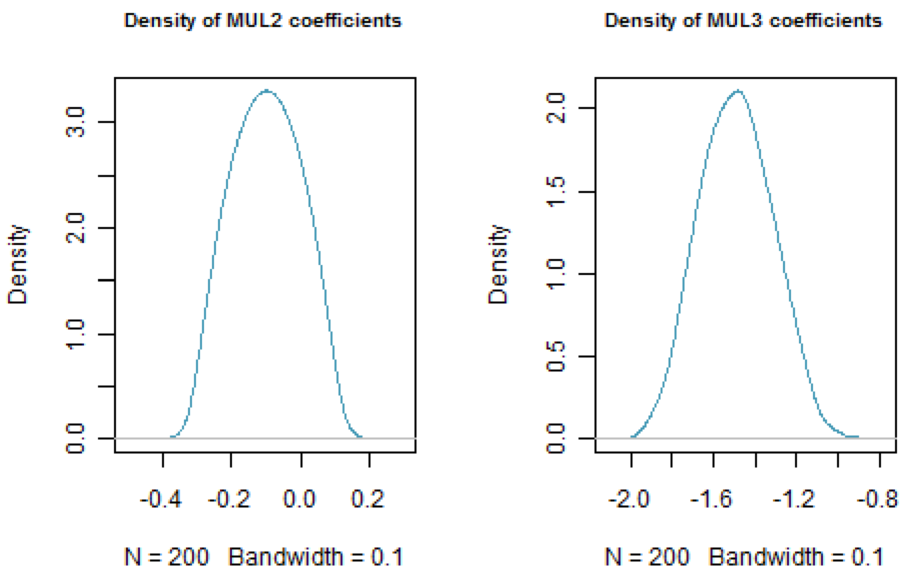


Figure C.3 Scatter-plots of MUL2 and MUL3 coefficients with spatial correlations

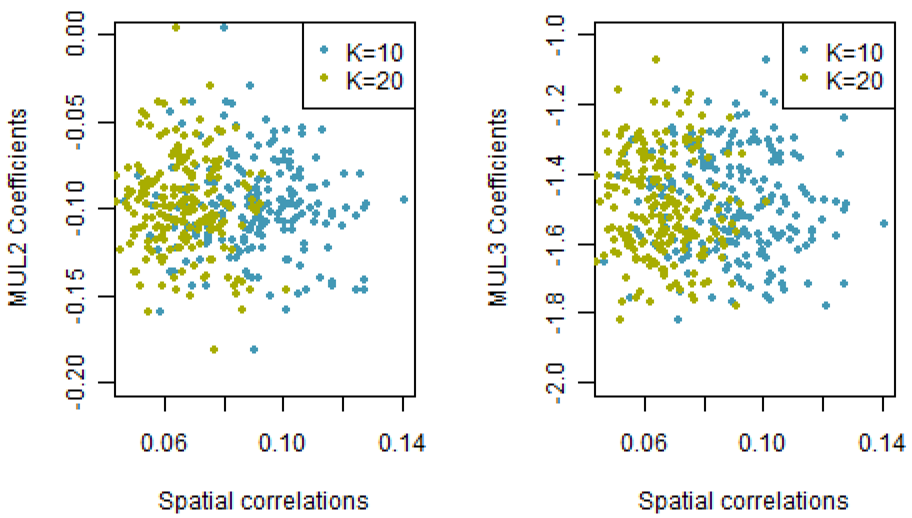
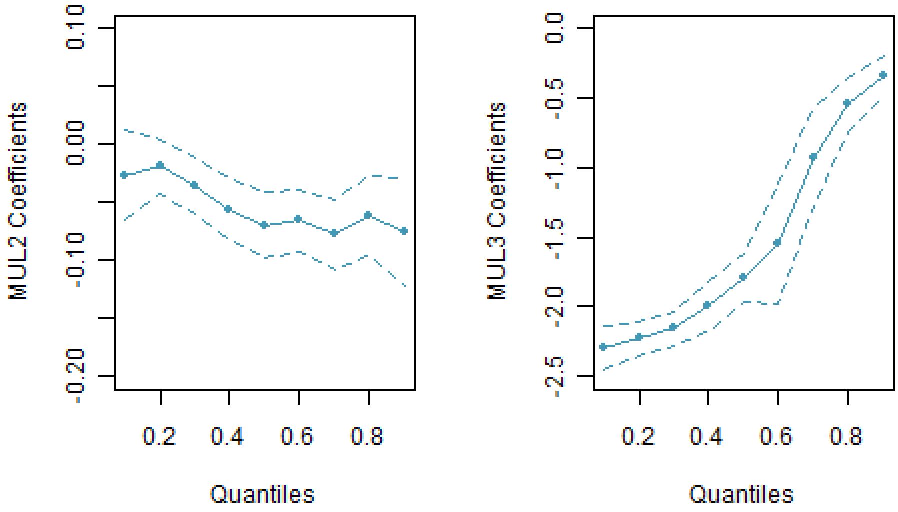


Figure C.4 Bootstrapped MUL2 and MUL3 coefficients



Note: Solid and dash lines represent estimates and 95% bootstrapped confidence interval