The Spatial Impact of Local Infrastructural Investment in New Zealand

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Abstract

In this paper we estimate the impact of local authority infrastructure spending in New Zealand using spatial econometric modelling, with the infrastructure spending itself endogenously determined. Utilizing data from the New Zealand Census and Local Authorities Finance data (1991-2008), aggregated to functional labour market areas, we formulate a simultaneous equations growth model of real income, population, land rent and public infrastructure investment. Estimation is conducted using a spatial 3SLS procedure. We find that an increase in local infrastructure spending increases population growth, real income and land values, but is itself endogenous and spatially correlated.

JEL codes

H54, J21, R12

Keywords

local infrastructure, economic growth, migration, land value, spatial spillover

Contents

1. Introduction

Public infrastructural investment has been widely used as a tool for regional economic development, motivated by the view that such infrastructure is an intermediate public good that plays an active role in the production process. It is expected that increasing the stock of public infrastructure in a region will improve the productivity of existing firms and induce new firms to locate in the region. Consequently, regional output and employment will grow (Lall, 2007). Endogenous growth suggests that it is even possible that the region's long-run growth rate will increase. Meta-analyses of the empirical research does indeed show that public expenditure on infrastructure benefits economic growth (Nijkamp and Poot, 2004; Bom and Lighthart, 2009). This is the case at both the national and regional levels.

Given the magnitude of these investments and the policy emphasis on them as tools for regional development, the role of infrastructure in economic growth has been the subject of considerable research in the fields of public policy, economics, and planning, dating back to Nurske (1953) and Hirschman (1958). The past several decades have seen an intensification of this interest with numerous studies taking their lead from the work of Aschauer (1989) and Biehl (1986) in which infrastructure enters as an input in an aggregate production function.

The earlier studies in this tradition found a strong productive effect of public infrastructure. For example, Aschauer (1989), Reich (1991) and Deno (1988) all found that the return to private sector economic performance from public investment was greater than from private investment. However, more recent research has raised serious concerns around the robustness of these empirical results (see Sturm et al. (1998) for an overview of this literature). In terms of the specification of regression models that explain the contribution of public infrastructure to regional output, it has been found that, when regional and temporal fixed effects are introduced, the effects of public sector investment on private sector productivity and output are either markedly reduced or disappear completely (Holtz-Eakin,1994; Hulten & Schwab, 1991; Garcia-Mila & McGuire, 1992). Moreover, when the spatial context in which public infrastructural investment occurs is taken into account, the magnitude and significance of the estimated effect of that investment decreases as well (Kelejian & Robinson, 1997).

A number of possible avenues exist by which public investment at one location may influence productivity and output at neighbouring locations. For instance:

- Public infrastructural investment in one region may induce mobile production factors to move to that region to avail themselves of the improved infrastructural endowments. This mechanism suggests that the output of a region would depend positively on its stock of infrastructure and negatively on the stock of infrastructure in the surrounding regions.
- Conversely, public infrastructure – especially that related to transportation – may have a

positive impact not only in the region where it is located but also on neighbouring regions due to the network characteristic of some infrastructure, in which any piece is subordinate to the entire network. For example, the building or expansion of a port or airport in one region may allow producers in neighbouring regions greater access to markets.

- In addition, the analysis of the effects of public infrastructural investment is usually carried out using data aggregated to administrative boundaries. These boundaries frequently poorly reflect functional economic areas or the networks that connect them. Linkages forward and backward are then not appropriately measured in the data and statistical spillover effects result from this measurement problem.

One approach to measuring the spatially varying impacts of infrastructure is the spatial equilibrium approach suggested by Haughwout (2002), which has been used to assess the impact of the Auckland northern motorway extension (see Grimes and Liang, 2010). This approach measures changes in land values at a highly disaggregated level, a mesh block.[1]

The approach that is adopted in the present paper complements this earlier research and considers the economic impact at a greater spatial level that is also of policy significance, namely that of the Labour Market Area (LMA) (defined below). This paper is therefore in the tradition of the macro-level impact studies cited above, but with the innovations of, firstly, using spatial econometrics to measure interregional spillover effects and, secondly, of identifying the drivers of local public investment.

The paper is structured as follows: section 2 covers the theoretical framework, the specification of our model and the methodology used to perform the estimation. Section 3 discusses the data used in this paper and outlines the rationale for the use of LMAs as the underlying spatial frame for the analysis. Section 4 reports the results of the standard 3 stage least squares (3SLS) procedure to estimate the parameters of our model and then compares these results with those of a recently developed spatial 3SLS procedure. Section 5 presents conclusions.

2. Model Specification and Methodology

The approach adopted here is to embed the impact of local infrastructure investment in a model of spatial equilibrium such as developed by Roback (1982) and Haughwout (2002). Spatial variation in unemployment rates and labour force participation remain in the background. A simple extension of the Roback (1982) model suffices to motivate the empirical relationships that we anticipate.[2] In the Roback model, capital and workers are perfectly mobile. However, land availability and amenities are location specific. Following an exogenous shock, workers will migrate between

[1] A mesh block is the smallest geographic unit for which statistical data is collected and processed by Statistics New Zealand. In urban areas it is about the size of a city block.

[2] See Moretti (2010) for a recent model of spatial equilibrium with heterogeneous labour and agglomeration.

regions until their utility is the same everywhere. Similarly, capital is moved across regions until the rate of return is the same everywhere. In the absence of differences in amenities across regions, wages and rents would also be equal everywhere but, as Roback (1982) shows, different levels of amenities across regions will lead to spatial differences in wages and rents. Amenities may be fixed and natural, such as related to the climate, or varying such as positive or negative externalities associated with population density, or the amenities provided by local government.

In this paper, we interpret local government-provided infrastructure as productive amenities. However, we will assume that the level of local infrastructure is endogenous. It is easy to show with the Roback model that an exogenous increase in productive amenities leads to higher rents, but has an ambiguous effect on wages. What would drive endogenous infrastructure investment? The simplest explanation is that most publicly provided services and infrastructure are congestible. Consequently, an increase in population leads to a lower quality of public services and greater congestion, and possibly outward migration of residents, unless some infrastructure investment is undertaken. With endogenous infrastructure and local authorities being the third set of behavioural agents in the model, a third equilibrium condition (besides equal utility and equal unit production costs across space) must be imposed. A plausible condition is a balanced budget (over-time) for local government spending, with local infrastructural and other outlays funded by local taxes, usually in the form of a property tax.

If local infrastructure investment is endogenous and productive, wages are expected to increase in response to an increase in infrastructure. This is illustrated in Figure 1 for the impacts of endogenous local authority spending. Consider a particular region in which the initial equilibrium land rent is r_1 and the wage is w_1 (point A). Following a positive productivity shock, the curve $C(w,r;s_1)$ will shift to the right, to $C'(w,r;s_1)$. Consequently, firms in the region will offer higher wages and rents will increase (point B). However, with endogenous public infrastructure spending this is not the new equilibrium. The positive productivity shock leads to greater employment, which requires inward migration. To avoid a decline in the quality of public services, the local government responds with increasing public amenities from s_1 to s_2. This shifts the cost equalization curve from $C'(w,r;s_1)$ to $C'(w,r;s_2)$. At the same time, there are two influences on the curve $V(w,r;s_1)$ that represents wage/rent combinations with spatially equalized utility. The first is that the additional public spending is likely to have spillover benefits for consumers (e.g., road infrastructure lowers travel times). This leads to a shift of V upwards. On the other hand, the local tax that needs to be raised lowers real disposable income, which shifts V to the right. The combined effect will be that the shift in V will be rather small, say between V^u and V^d. The new equilibrium is somewhere along the bold segment in Figure 1.

The outcome as displayed in Figure 1 leads to the conclusion that a positive productivity shock is expected to raise land rent in spatial equilibrium, increases the population of the region through net inward migration, increases the level of public infrastructure investment, and increases wages. If the greater population subsequently enhances productivity growth further through agglomeration advantages (with the congestion externalities being partly offset by additional local government spending) a positive feedback loop has been created of self-reinforcing growth associated with inward migration.[3]

The simple endogenous processes described above suggest a growth model of four equations: one each for growth in public infrastructure capital, change in real income, population change, and lastly change in the real value of land. Each equation is estimated using data for 58 LMAs across two time periods (1996-2001 and 2001-2006).

The first equation, for growth in public infrastructure capital (Δ_Infrastructure), is estimated as a function of a period dummy controlling for national business cycle effects (Period_dummy) and variables for the percentage change in real median income (Δ_Income), the percentage change in the usually resident population (Δ_Population), initial homeownership (%_Homeownership_1996), the interaction of the period dummy with initial homeownership (Period*Homeown) and the percentage change in estimated real land value (Δ_Landvalue).

The real income growth variable (Δ_Income) is included as an explanatory variable since the growth in public infrastructure capital is anticipated to be positively related to real income growth. This reflects investment being a function of the change in the level of output (i.e. the accelerator principle), with real income growth proxying for real regional GDP growth[4].

Population change (Δ_Population) plays a crucial role in the determination of public infrastructure investment as both local and central government use this easily measurable variable as the basis for both funding and planning.

Roskruge et al (2010) found homeowners tend to be more critical of local authorities than renters, potentially demanding higher provision of services, thus driving local authorities to invest more heavily in public infrastructure. The homeownership variable (%_Homeownership_1996) is used to capture this effect with the value from the start of the period under consideration (1996) being used to avoid problems with endogeneity. As with the other time-interacted variables in the system of equations, the interaction of the homeownership variable with the period dummy allows the coefficient on this variable (Period*Homeown) to vary between periods.

The change in real land value variable (Δ_Landvalue) is of particular significance in the New Zealand context as nearly 60 percent of local services are funded from property taxes (McLuskey et al, 2006).

[3] A recent meta-analysis suggests that an increase in the rate of net internal migration by one percentage point, raises the rate of real income growth by 0.1 percentage points. This is consistent with the suggested self-reinforcing growth (Ozgen et al. 2010).

[4] Official estimates of sub national GDP are not available for New Zealand.

The equation for change in real income per capita explains economic growth in terms of the growth in public infrastructure capital (Δ_Infrastructure), the percentage change in usually resident population (Δ_Population), the natural logarithm of median income at the beginning of the period (log_Income_1996), the interaction of the period dummy and the income variable (Period*Income), the local unemployment rate (%_Unemployed_1996), the interaction of the local unemployment rate and the period dummy (Period*Unemployed) and a period effect (Period_dummy).

Growth in public infrastructure capital (Δ_Infrastructure) is expected to induce real per capita income growth through both Keynesian demand effects and neoclassical productivity effects, while the inclusion of the percentage change in usually resident population (Δ_Population) is supported by the meta analysis of Ozgen et al (2010) who found that population growth was positively related to income growth when due to net inward migration.

We expect a negative sign on the parameter estimate of the log of real income at the beginning of the period (log_Income_1996) (beta convergence) as the standard neoclassical growth model posits that income growth is inversely related to the initial level of income (Barro & Sala-i-Martin, 1992).

Assuming an Okun's law like relationship between unemployment and real income growth (Lee, 2000), real income growth will be reduced as unemployment rises. We therefore expect a negative sign on the local unemployment rate (%_Unemployed_1996) parameter.

The variables growth in public infrastructure capital (Δ_Infrastructure), change in overseas born population (Δ_Overseas_Born),[5] industry mix (Industry_Mix), the natural logarithm of the median real income (log_Income_1996), the interaction of the period dummy and the income variable (Period*Income), the percentage unemployed (%_Unemployed_1996), the interaction of the local unemployment rate and the period dummy (Period*Unemployed), and the period dummy (Period_dummy) enter into the equation for population growth (Δ_Population).

It is anticipated that investment in public infrastructure capital (Δ_Infrastructure) will have a positive relationship with population growth as such investment may make an area relatively more attractive to reside in, inducing in-migration.

Population growth through net migration has long been associated with prevailing labour market conditions, with real income levels (log_Income_1996) and employment opportunities (Industry_Mix) being positively related to these flows (see Boyle et al, 1998; Greenwood, 1997; Molho, 1986; Poot, 1986). Unemployment is also frequently positively associated with net migration, not because migrants perversely wish to lower their probability of employment and earnings but because of high labour turnover in such areas attracting migrants (Poot, 1986).

[5] International migration is proxied here by the five-yearly change in the percentage of overseas born persons in an LMA.

The equation for the percentage change in real land value consists of the variables for growth in public infrastructure capital (Δ_Infrastructure), the natural log of the estimated real land value at the beginning of the period (log_landvalue_1996), the interaction of the land value and the period dummy (period*landvalue), percentage change in usually resident population (Δ_Population), and the period dummy (period_dummy).

Real land values are hypothesised to increase with investment in public infrastructure; hence we expect a positive sign on the parameter for growth in public infrastructure capital (Δ_Infrastructure) due to positive externalities stemming from such investments. For instance, accessibility of areas may improve with investment in roading, leading to more demand for land in those areas and hence higher real land values.

Spatial differences in amenities will lead to persistent spatial differences in the value of land. However, on the long-run growth path there may be neoclassical convergence, in which case we expect a negative sign on the parameter estimate for the natural log of estimated real land value (log_landvalue_1996). Lastly, increases in population (Δ_Population) will lead to increased demand for land for residential purposes.

In a recent article, Wu and Gopinath (2008) examine the causes of spatial disparities in economic development in the United States using a two-step procedure based on the general approach of Kelejian and Prucha (2004). Firstly, a system of simultaneous equations, being structural equations of demand and supply in the labour and housing markets, is estimated using a 3SLS estimator, thus correcting for endogeneity and contemporaneous correlation. In the second step of the procedure the residuals from the 3SLS estimation were tested for spatial auto-correlation. If spatial auto-correlation is identified in an equation, the 3SLS residuals are used to estimate the spatial correlation parameter (ϱ) by means of the generalised moment estimator suggested by Kelejian and Prucha (1999). The data are then transformed using the matrix (I-ϱW) where I is an NxN identity matrix, N being the number of observations, and W a spatial weights matrix. Using the transformed data, each equation is then re-estimated using the ordinary least squares estimator (OLS).

In this paper we face a similar problem, the estimation of a system of equations representing the growth path of regional economies in the presence of spatial auto-correlation. We adopt a somewhat different approach from Wu and Gopinath (2008). Initially the four-equation growth model (one equation each for growth in public infrastructure capital, change in real income, population change and change in the real value of land) is estimated using standard 3SLS.[6] In performing this estimation we are confronted with an issue arising from the endogenous determination of two explanatory variables, homeownership and unemployment. One avenue for dealing with this issue is to use

[6] All estimations were carried out in Stata 11 using either the reg3 command (3SLS), the spatreg command (invoking the spatial procedures provided by Maurizio Pisati) or the splagvar commands of P. Wilner Jeanty.

beginning of period values (i.e. 1996 values for the 1996-2001 period and 2001 values for the 2001-2006 period). However, while this might be satisfactory for the first period (1996-2001) it is not for the second as the values for 2001 would be endogenously determined with the 1996-2001 change variables. Instead, for both time periods, homeownership and unemployment are entered as their 1996 values and as their 1996 value interacted with the time period dummy.[7]

The residuals of each of the estimated equations are then inspected for the presence of spatial autocorrelation. Where the residuals of a particular equation show a significant level of spatial autocorrelation, the spatial lag of the dependent variable is created. Next, the 3SLS system was re-estimated with the inclusion of the spatially lagged variables in the relevant equations. The inclusion of the spatially lagged dependent variables in the 3SLS system can be seen as analogous to the use of the Spatial Autoregressive (SAR) model in the single equation context (see Lesage and Pace, 2009, pg 32-33).

The observations in all models were weighted by the LMA's usually resident population for the beginning of the period in question. Given that many of the variables represent average outcomes for individuals and households within LMAs, such as the percentage of labour force that is unemployed, a control for heteroscedasticity was introduced by means of analytical weights that were equal to the population size of each LMA. [8]

3. Data and descriptives

The data used in this paper are drawn from a number of sources covering the two periods 1996-2001 and 2001-2006:

• The quinquennial New Zealand Census of Population and Dwellings,

• Motu's Quotable Value New Zealand (QVNZ) sales and valuation database,

• Motu's Regional and Local Authorities Finance database,

• Statistical profiles of individual councils available from the Department of Internal Affairs at http://www.localcouncils.govt.nz/lgip.nsf.

These data were aggregated to Labour Market Areas (LMA) which were built up from census area unit[9] (CAU) level. It has long been recognized that functional economic areas are the most appropriate unit of analysis for examining regional economic activity (Stabler and Olfert, 1996, p. 206) as administrative areas such as Regional Councils or territorial authorities tend to be rather arbitrary in terms of their boundaries in so far as they reflect economic relations. Administrative areas have largely

[7] We also follow this procedure for the inclusion of income and land value in equations that test for regional convergence.
[8] Analytical weights can be used with most Stata regression commands, but not with spatreg.
[9] Census area units are the second smallest geographic area used by Statistics New Zealand and are comprised of a number of mesh blocks. In urban areas they usually contain between 3000-5000 persons.

served as the basis for most regional analysis in the past as most official statistics have been gathered or aggregated to administrative boundaries. However, it is now possible to build up regional data with any defined boundaries from very small geographical units of measurement, using GIS and related systems.

Consequently, there has been growth in the use of functional economic areas, notably in the analysis of various labour market phenomena (see, for instance, Casado-Diaz, 2000; Newell and Papps, 2001; ONS and Coombes, 1998). Newell and Papps (2001) used travel to work data from the 1991 and 2001 censuses to define LMAs in New Zealand. This research yielded 140 LMAs for 1991 and 106 for 2001. This level of breakdown is too refined for linking to regional characteristics that come from sources other than the census. A level of disaggregation that permits the building up of a regional analysis with a wide range of regional indicators is that of 58 LMAs. The boundaries and names of these LMAs are shown in Figure 2.

Turning to the derivation of the main dependent variables: Total additions to public fixed capital in the LMA were estimated on the basis of reported Territorial Authority (TA) and Regional Council (RC) additions to infrastructure capital, apportioned to their constituent CAU on the basis of population, then re-aggregated to the LMA level. It should be noted that estimates of fixed capital stocks of public infrastructure are unfortunately not available in New Zealand. Hence we only have information on additions to stocks of infrastructure capital rather than the stocks themselves.

Growth in infrastructural capital was assumed to be proportional to the investment ratio (I/Y*100). This ratio was calculated by dividing the sum of total additions to fixed capital (I) in the LMA by Territorial Authorities (TA) and Regional Councils (RC) by LMA aggregate income (Y). The latter was proxied by the mean personal income in the LMA multiplied by the usually resident population aged 15 years and over.

Figure 3 and Figure 4 show the spatial distribution of growth in infrastructural capital for the 1996-2001 and 2001-2006 periods, respectively. The Moran's *I* statistics for both periods are positive and significant (I=0.156, p<.05), indicating the clustering of similar values of infrastructural growth. For the 1996-2001 period, infrastructural capital growth rates range from about 1.5 percent (Hutt Valley) to 28 percent (Queenstown) while for the 2001-2006 period the range is similar, ranging from 1.7 percent (Hutt Valley) to 28 percent (Queenstown) with growth rates in the two periods being strongly correlated (r=.65, p <.01).

The percentage change in real median income (NZ$2006) was calculated from the census meshblock database aggregated to LMA boundaries for the 1996, 2001 and 2006 censuses. For the first period, 1996-2001, percentage change in real median income ranged from a decline of around 1 percent in Bulls to an increase of approximately 17 percent in Kaikohe while in the second period the percentage change in real median income ranged from just under 1 percent in Tokoroa to nearly 25 percent in Alexandra. Interestingly, the correlation in growth in median income between the two periods was insignificant. The Moran's *I* for the period was significant and positive (I=.168, p<.05); however for the second period *I* was not significant (I=.079, p>.1) indicating that in the latter period growth in real median income was geographically relatively uniformly distributed. Figures 5 and 6 show the spatial distribution of the percentage change in real median income for the two periods.

Percentage inter census change in usually resident population was again calculated on the basis of census counts aggregated to LMA boundaries. The spatial distribution of the percentage inter census changes in usually resident population are shown in Figures 7 and 8 for the 1996-2001 and 2001-2006 periods respectively. The Moran's *I* for both periods were significant and positive (1996-2001, I=.212, p<.01; 2001-2006, I=.253, p<.001). For the first period, population growth varied between a decline of nearly 14 percent in Taihape and an increase of 16 percent in Tauranga with over half (35) of the LMAs experiencing population declines. In the second period, population growth ranged between a decline of 5 percent in Eketahuna and an increase of nearly 30 percent in Queenstown with only a quarter of LMAs experiencing population declines. Population growth between the two periods was highly correlated (r=.798, p<.05).

To obtain the percentage change in estimated real land value, the land values were estimated by multiplying the CAU level mean sales price by the ratio of land valuation to capital valuation for each census year. The CAU estimates were then aggregated to LMA level, weighted by the number of dwellings in each CAU and converted to NZ$2006 dollars. The percentage change for the inter-censal period was then calculated. In the first period, percentage change in land values ranged from a decline of nearly 50 percent in Waipukurau to an increase of close to a 100 percent in Eketahuna. There was a moderate negative correlation between the percentage change in estimated real land value in the first and second periods (r=-.416, p<.05). In the second period the largest, and only, decline was that of Eketahuna (-14 percent) while in the MacKenzie LMA real land values increased by nearly 380 percent. Figures 9 and 10 show the spatial distribution of percentage change in estimated real land value. The Moran's *I* for both periods is significant and positive (1996-2001, I=.200, p<.01; 2001-2006, I=.129, p<.05) though *I* is considerably smaller in the second period.

The industry mix variable is the industry mix effect calculated by the classical shift share technique (Cochrane and Poot, 2008). Definitions for all variables used in this analysis can be seen in Table 1 with their accompanying descriptive statistics shown in Table 2.

Finally, before we turn to the estimation results, we must consider the construction of the spatial weights matrix used to specify the spatial relation between LMAs. Although the selection of the spatial weights matrix is a crucial decision in a spatial econometric analysis, there exists no clear cut means of deciding on which approach to use (Griffith, 1996, p 65).[10] The difficulties entailed in this

[10] Stetzer (1982) and Florax and Rey (1995) find that over-specification of the spatial weights matrix leads to a loss of statistical power while under-specification induces an increase in power in the presence of positive spatial auto

decision are compounded by the plethora of different specifications available. Getis and Aldstadt (2004) identified no fewer than eight commonly used methods and a wide range of lesser known ones, while Conley & Topa (2002) expand the number of possibilities to include non-spatial metrics.[11]

In this paper the weights matrix is constructed on the basis of the reciprocal of the squared travel time between the major urban centres of each LMA. The matrix takes a block diagonal form. Effectively, LMAs in one time period form an interacting block with no neighbours in another time period. Alternatively this can be interpreted as there being an infinite distance between any LMAs in a specific time period and all other LMAs at other points in time. Before carrying out the spatial regressions, the weights matrix has been row standardized.

4. Results

The results of the non-spatial 3SLS system are presented in Table 3.[12] Two variables attain significance at the 5 percent level (with positive coefficients) in the growth in public infrastructure capital (Δ _Infrastructure) equation. The variable for percentage change in median income (Δ_Income) is significant, which suggests that growth in real income in a region leads to an increase in investment in public capital. Secondly, the percentage change in estimated real land value (Δ_Landvalue) is also significant, in line with the expected importance of land taxes (rates) in funding local infrastructural investment. The other variables are all statistically insignificant though of the expected sign. It would seem that the spatial distribution of investment in public infrastructure is rather haphazard in New Zealand, possibly more determined by funding availability and political factors rather than conventional economic drivers.

In the change in real income (Δ_Income) equation the population change variable (Δ_Population) and the growth in public infrastructure capital (Δ_Infrastructure) variable are significant and positive. Infrastructure growth increases productivity and, consequently, real income, as the work of Aschauer (1989) and others suggested. Moreover, population growth also provides a boost to real income growth, which is consistent with the recent meta-analysis of Ozgen et al. (2010).

Regional population growth is positively affected by investment in public infrastructure (Δ_Infrastructure), international migration (Δ_Overseas_Born), a favourable mix of industries (Industry_Mix), and income in the latter period. In addition, unemployment in the second period is associated with high levels of population growth, perhaps due to greater labour market churn in such

correlation and a loss in power in the presence of negative spatial correlation. Both under- and over-specification produce an increase in the mean squared error for spatial econometric models (Griffith, 1996, p 66-67).

11 Getis and Aldstadt cite bandwidth distance decay, Gaussian distance decline and tri-cube distance decline functions as examples. To this list should be added their own AMOEBA methodology (Getis & Aldstadt, 2004)

12 In Tables 3, 5 and 7 rather than reporting the interaction terms directly, the parameter on the variable of interest in the latter period is reported. For instance in the equation for the percentage change in real land value rather than reporting the parameter on the interaction term for land value and the period dummy (period*landvalue) what is reported is the parameter on land value in the 2001-2006 period. This is simply obtained by adding the parameter estimate obtained for the first period to that of the interacted term. The motivation for this was to assist in interpretation of the results.

areas. The period dummy is negative even though population growth in the latter period was more than in the earlier one (see Table 2). However, as the equation includes a term to capture the effects of international migration (Δ_Overseas_Born), this may reflect the fact that natural increase in the population of New Zealand was relatively lower in the second period with overall population growth being driven by international migration.

Lastly, the variable for investment in public infrastructure (Δ_Infrastructure) attains significance for the change in real value of land (Δ_Landvalue), as does the lagged log of real land value in the second period and the period dummy itself.

Table 4 shows the Moran's *I* statistics for the residuals from the non-spatial 3SLS. Except for the inter census change in usually resident population, Moran's *I* for the residuals of the non-spatial 3SLS estimation are positive and significant at the 5 percent level indicating that spatial auto correlation is a problem in these instances.[13] Accordingly, the 3SLS system is re-estimated including spatial lags on the dependent variables in the growth in public infrastructure capital (Δ_Infrastructure), change in real income (Δ_Income) and change in real value of land (Δ_Landvalue) equations.

The results of the spatial 3SLS model are shown in Table 5 along with the Moran's *I* statistics for the residuals (Table 6), while Table 7 compares the results of the non-spatial and spatial 3SLS.

In the public infrastructure capital (Δ_Infrastructure) equation, the percentage change in median income (Δ_Income) variable remains significant and positive, though of a somewhat smaller magnitude. The estimated real land value (Δ_Landvalue) variable is still positive, but no longer significant. In addition, the spatial lag of the growth in public infrastructure capital (Δ_Infrastructure) is significant and positive indicating that growth in infrastructure spending in one region spending spills over into surrounding areas.

For the real income (Δ_Income) equation, the population change variable (Δ_Population) and the growth in public infrastructure capital (Δ_Infrastructure) variable remain significant and positive although the estimated parameter values are between a third and a quarter lower than in the non-spatial 3SLS.

Turning to the regional population growth equation from the spatial 3SLS model, we find that the parameter estimates for public infrastructure (Δ_Infrastructure), international migration (Δ_Overseas_Born), industry mix (Industry_Mix), and the log income term for the latter period all remain significant, positive and of similar magnitude to those obtained in the non-spatial 3SLS. The period dummy (Period_dummy) also remains significant, of a similar magnitude and retains a negative sign.

[13] Cliff and Ord (1981, p. 200-206) and Schabenberger and Gotway (2005, p. 314-315) discuss the problem of assessing spatial auto correlation in regression residuals using Moran's *I*.

In the final equation of the system, for the change in real value of land (Δ_Landvalue), the lagged log of real land value in the second period and the period dummy remain significant and of similar magnitude to the estimates obtained in the non-spatial 3SLS while the variable for investment in public infrastructure (Δ_Infrastructure) remains positive but ceases to be significant at 5% (p=0.125).

Table 6 reports Moran's *I* statistics for the residuals of the spatial 3SLS estimation. This indicates that the inclusion of the spatial lags in the growth in public infrastructure capital (Δ_Infrastructure), change in real income (Δ_Income) and change in real value of land (Δ_Landvalue) equations has reduced the impact of spatial auto correlation with none of the Moran's *I* for the 3SLS equations being significant.

5. Conclusions

In this paper we estimated the impact of local authority infrastructure spending in New Zealand using spatial econometric modelling techniques. Both the spatial and non-spatial 3SLS estimators told a similar story, indicating that the spatial distribution of investment in public infrastructure may be rather haphazard in New Zealand, possibly more determined by funding availability and political factors rather than conventional economic drivers. There is significant spatial dependence in infrastructure with clear evidence that growth in infrastructural spending in an area spills over into surrounding regions.

The results support the presence of self-reinforcing growth processes: real income growth is positively affected by both infrastructure growth and population growth, while real income growth itself contributes to growth in infrastructure spending. The equation for population growth is consistent with theories of migration. Finally, there is some weaker evidence that increased infrastructure investment is reflected positively in land values. These findings are all in accordance with our extensions to Roback's spatial equilibrium model, confirming that positive two-way interactions exist between infrastructure investment and regional economic outcomes.

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Appendix

Table 1 Variable Definitions

	Variable	Definition
Endogenous	Δ_Income	Change in real median income (percent)
	Δ_Infrastructure	Estimated growth in infrastructure capital (see following slide)
	Δ_Landvalue	Change in estimated real land value (percent)
	Δ_Population	Percentage change in usually resident population over the inter census period
Exogenous	%_Homeownership _1996	Percent Home ownership
	%_Unemployed_1996	Percentage of labour force that is unemployed in 1996
	Industry_Mix	Industry mix effect
	log_Income_1996	Natural logarithm of real median income $2006
	log_Landvalue_1996	Natural log of estimated real land value $2006 (see following slide)
	Period*Homeown	Interaction of %_Homeownership and the period dummy
	Period*Income	Interaction of log_Income_1996 and the period dummy
	Period*Landvalue	Interaction of log_Landvalue_1996 and the period dummy
	Period*Unemployed	Interaction of %_Unemployed_1996 and the period dummy
	Period_dummy	0=1996-2001, 1=2001-2006
	Δ_Overseas_Born	Change in overseas born population (percent)
Instruments	%_Degree_Plus	Percentage with Bachelors degree or better
	%_Maori	Percentage Maori
	%_Professionals	Percentage in professional occupations
	%_Smokers_1996	Percentage smokers 1996
	Dependency_Ratio	Demographic dependency ratio ((0-14 plus 65+) / (15-64))
	Km_to_Auckland	Distance to Auckland (Km)
	Period*Population_Density	Interaction of Population_density and the period dummy
	Population_density	LMA population density (population per km2)
	Rainfall	Rainfall (ml) largest urban area in LMA (20 yr average)
	Δ_Income	Change in real median income (percent)
	Δ_Infrastructure	Estimated growth in infrastructure capital (see following slide)
	Δ_Population	Percentage change in usually resident population over the inter census period
	Δ_Landvalue	Change in estimated real land value (percent)

Table 2 Descriptive statistics by period (population weighted)*

		Period beginning 1996				Period beginning 2001			
	Variable	mean	sd	min	max	mean	sd	min	max
Endogenous	Δ_Income	5.85	2.29	-0.71	16.94	11.59	3.02	0.75	24.52
	Δ_Infrastructure	8.21	2.59	1.45	28.05	9.69	3.01	1.70	27.54
	Δ_Landvalue	15.64	18.51	-47.61	96.32	95.91	43.11	-13.97	376.07
	Δ_Population	3.29	5.43	-13.52	16.44	7.78	5.21	-5.2	28.99
Exogenous	%_Homeownership _1996	70.54	3.33	51.97	79.24	70.51	3.28	51.97	79.24
	%_Unemployed_1996	7.81	1.89	2.37	18.87	7.80	1.86	2.37	18.87
	Industry_Mix	-0.06	1.84	-5.71	3.42	-0.07	2.52	-7.82	3.62
	log_Income_1996	9.94	0.11	9.47	10.15	9.94	0.11	9.47	10.15
	log_Landvalue_1996	11.03	0.68	8.89	12.00	11.06	0.67	8.89	12.00
	Δ_Overseas_Born	12.39	9.46	-10.9	38.73	24.53	9.39	-2.37	69.34
Instruments	%_Degree_Plus	9.44	4.79	3.21	21.46	11.59	5.3	3.83	23.8
	%_Maori	13.64	7.99	4.51	52.59	13.41	8.13	4.39	55.42
	%_Professionals	22.44	5.34	9.77	33.87	24.74	5.96	10.49	36.65
	%_Smokers_1996	23.83	3.12	20.5	37.05	23.75	3.08	20.5	37.05
	Dependency_Ratio	53.35	6.29	34.21	69.84	53.52	6.76	35.48	71.12
	Km_to_Auckland	474.13	482.5	0.00	1638	461.05	479.06	0.00	1638
	Population_density	63.09	85.23	0.45	321.25	64.33	85.49	0.45	321.25
	Rainfall	1123.02	293.89	360.00	2430.00	1124.78	289.7	360.00	2430.00

*Weighted by LMA usually resident population at commencement of period

Table 3 Non-Spatial 3SLS

Equation	Obs	Parms	RMSE	R-sq	chi2	P
Estimated growth in infrastructure capital	116	6	2.81	0.051	52.44	.000
Change in real median income	116	7	2.75	0.506	214.17	.000
Inter census change in usually resident	116	8	2.14	0.861	800.87	.000
Change in estimated real land value	116	5	26.839	0.734	317.51	.000

Estimated growth in infrastructure capital						
	Coef.	**Std. Err.**	**z**	**P>z**	**[95% Conf. Interval]**	
Δ_Income	0.628	0.125	5.010	0.000	0.383	0.873
Δ_Population	0.037	0.057	0.640	0.519	-0.075	0.149
%_1996 Homeownership, 1996-01 coeff	0.078	0.091	0.850	0.394	-0.101	0.256
%_1996 Homeownership, 2001-06 coeff	0.028	0.156	0.179	0.858	-0.278	0.333
Δ_Landvalue	0.026	0.011	2.290	0.022	0.004	0.048
Period_dummy	-0.807	8.914	-0.090	0.928	-18.278	16.664
Constant	-1.469	6.585	-0.220	0.823	-14.375	11.437
Change in real median income						
Δ_Infrastructure	0.610	0.162	3.760	0.000	0.292	0.928
Δ_Population	0.137	0.064	2.130	0.033	0.012	0.262
log_Income_1996, 1996-01 coeff	2.031	3.593	0.570	0.572	-5.011	9.073
log_Income_2001, 2001-06 coeff	-3.500	5.645	-0.620	0.535	-14.564	7.564
%_Unemployed_1996, 1996-01 coeff	0.004	0.176	0.020	0.981	-0.341	0.349
%_Unemployed_1996, 2001-06 coeff	-0.196	0.300	-0.653	0.516	-0.784	0.392
Period_dummy	60.755	44.197	1.370	0.169	-25.870	147.380
Constant	-19.830	36.955	-0.540	0.592	-92.260	52.600
Inter census change in usually resident population						
Δ_Infrastructure	0.519	0.139	3.730	0.000	0.247	0.791
Δ_Overseas_Born	0.414	0.027	15.560	0.000	0.361	0.467
Industry_Mix	0.474	0.130	3.660	0.000	0.219	0.729
log_Income_1996, 1996-01 coeff	5.284	3.421	1.540	0.122	-1.421	11.989
log_Income_1996, 2001-06 coeff	18.403	5.247	3.508	0.000	8.120	28.686
%_Unemployed_1996, 1996-01 coeff	0.224	0.164	1.370	0.170	-0.097	0.545
%_Unemployed_1996, 2001-06 coeff	0.852	0.280	3.042	0.002	0.303	1.401
Period_dummy	-136.599	40.415	-3.380	0.001	-215.811	-57.387
Constant	-60.335	34.971	-1.730	0.084	-128.877	8.207
Change in estimated real land value						
Δ_Infrastructure	4.140	1.386	2.990	0.003	1.423	6.857
Log_Landvalue_1996, 1996-01 coeff	1.024	8.161	0.130	0.900	-14.971	17.019
Log_Landvalue_1996, 2001-06 coeff	-34.788	10.976	-3.169	0.002	-56.301	-13.275
Δ_Population	-0.020	1.001	-0.020	0.984	-1.982	1.942
Period_dummy	470.428	81.592	5.770	0.000	310.511	630.345
Constant	-29.593	90.221	-0.330	0.743	-206.423	147.237

NB: Grey shading indicates significance at 5 percent level

Endogenous variables: Δ_Infrastructure, Δ_Income, Δ_Population, Δ_Landvalue

Exogenous variables: %_Homeownership _1996, Period*Homeown, Period_dummy, lag_log_Income_1996, log_Income_1996, Period*Income, %_Unemployed_1996 , Period*Unemployed, Industry mix effect, lag_log_Landvalue_1996, log_Landvalue_1996, Period*Landvalue, %_Maori Rainfall, %_Professionals, %_Degree_Plus, %_Smokers_1996, Km_to_Auckland, Population_density, Period*Population_Density, Dependency_Ratio, Δ_Overseas_Born

Table 4

Moran's I

Variables	I	E(I)	sd(I)	z	p-value*
Estimated growth in infrastructure capital	0.107	-0.009	0.060	1.921	0.027
Change in real median income	0.093	-0.009	0.061	1.663	0.048
Inter census change in usually resident population	0.061	-0.009	0.061	1.140	0.127
Change in estimated real land value	0.107	-0.009	0.060	1.908	0.028

Table 5 Spatial 3SLS

Equation	Obs	Parms	RMSE	R-sq	chi2	P
Estimated growth in infrastructure capital	116	7	2.570	0.205	54.42	.000
Change in real median income	116	8	2.547	0.577	210.24	.000
Inter census change in usually resident	116	8	2.131	0.862	807.85	.000
Change in estimated real land value	116	6	26.772	0.735	312.51	.000

	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Estimated growth in infrastructure capital						
Lag_Δ_Infrastructure	0.415	0.128	3.250	0.001	0.164	0.666
Δ_Income	0.490	0.125	3.920	0.000	0.245	0.735
Δ_Population	0.016	0.057	0.280	0.781	-0.096	0.128
%_1996 Homeownership, 1996-01coeff	0.024	0.094	0.250	0.800	-0.160	0.208
%_1996 Homeownership, 2001-06coeff	-0.005	0.161	-0.031	0.975	-0.321	0.311
Δ_Landvalue	0.016	0.011	1.420	0.154	-0.006	0.038
Period_dummy	-1.540	9.125	-0.170	0.866	-19.425	16.345
Constant	0.065	6.703	0.010	0.992	-13.073	13.203
Change in real median income						
Lag_Δ_Income	0.076	0.141	0.540	0.590	-0.200	0.352
Δ_Infrastructure	0.430	0.163	2.630	0.009	0.111	0.749
Δ_Population	0.157	0.064	2.440	0.015	0.032	0.282
log_Income_1996,1996-01 coeff	2.504	3.697	0.680	0.498	-4.742	9.750
log_Income_2001, 2001-06 coeff	-4.867	5.790	-0.841	0.400	-16.215	6.481
%_Unemployed_1996, 1996-01 coeff	-0.019	0.182	-0.110	0.915	-0.376	0.338
%_Unemployed_1996, 2001-06 coeff	-0.224	0.312	-0.717	0.473	-0.836	0.388
Period_dummy	78.865	45.205	1.740	0.081	-9.735	167.465
Constant	-23.388	37.995	-0.620	0.538	-97.857	51.081
Inter censusal change in usually resident population						
Δ_Infrastructure	0.515	0.134	3.850	0.000	0.252	0.778
Δ_Overseas_Born	0.412	0.026	15.700	0.000	0.361	0.463
Industry_Mix	0.490	0.129	3.790	0.000	0.237	0.743
log_Income_1996,1996-01 coeff	5.440	3.390	1.600	0.109	-1.204	12.084
log_Income_1996, 2001-06 coeff	18.411	5.215	3.530	0.000	8.190	28.632
%_Unemployed_1996, 1996-01 coeff	0.217	0.163	1.330	0.183	-0.102	0.536
%_Unemployed_1996, 2001-06 coeff	0.846	0.279	3.036	0.002	0.300	1.392
Period_dummy	-135.114	40.273	-3.350	0.001	-214.048	-56.180
Constant	-61.764	34.639	-1.780	0.075	-129.655	6.127
Change in estimated real land value						
Lag_Δ_Landvalue	0.064	0.115	0.550	0.579	-0.161	0.289
Δ_Infrastructure	2.179	1.418	1.540	0.125	-0.600	4.958
Log_Landvalue_1996, 1996-01 coeff	-0.498	8.502	-0.060	0.953	-17.162	16.166
Log_Landvalue_1996, 2001-06 coeff	-37.416	11.991	-3.120	0.002	-60.918	-13.914
Δ_Population	0.426	1.020	0.677	0.677	-1.573	2.425
Period_dummy	477.405	99.404	4.803	0.000	282.577	672.233
Constant	0.539	93.937	0.995	0.995	-183.574	184.652

NB: Grey shading indicates significance at 5 percent level

Endogenous variables: Δ_Infrastructure, Δ_Income, Δ_Population, Δ_Landvalue

Exogenous variables: lag_infrastructure, %_Homeownership _1996, Period*Homeown, Period_dummy, lag_log_Income_1996, log_Income_1996, Period*Income , %_Unemployed_1996 Period*Unemployed, Industry mix effect, lag_log_Landvalue_1996, log_Landvalue_1996, Period*Landvalue , %_Maori, Rainfall, %_Professionals, %_Degree_Plus, %_Smokers_1996, Km_to_Auckland, Population_density, Period*Population_Density, Dependency_Ratio, Δ_Overseas_Born

Table 6

Moran's I

Variables	I	E(I)	sd(I)	z	p-value*
Estimated growth in infrastructure capital	0.012	-0.009	0.06	0.337	0.368
Change in real median income	0.070	-0.009	0.061	1.288	0.099
Inter census change in usually resident population	0.061	-0.009	0.061	1.136	0.128
Change in estimated real land value	0.083	-0.009	0.06	1.519	0.064

Table 7 Comparison of Non-Spatial and Spatial 3SLS

	Non Spatial 3SLS		Spatial 3SLS	
Equation	**R-sq**	**P**	**R-sq**	**P**
Estimated growth in infrastructure capital	0.051	0.000	0.205	0.000
Change in real median income	0.506	0.000	0.577	0.000
Inter census change in usually resident population	0.861	0.000	0.862	0.000
Change in estimated real land value	0.734	0.000	0.735	0.000
Estimated growth in infrastructure capital				
	Coef.	**P>z**	**Coef.**	**P>z**
Lag_Δ_Infrastructure			0.415	0.001
Δ_Income	0.628	0.000	0.490	0.000
Δ_Population	0.037	0.519	0.016	0.781
%_1996 Homeownership 1996-01 coefficient	0.078	0.394	0.024	0.800
%_1996 Homeownership 2001-06	0.028	0.858	-0.005	0.975
Δ_Landvalue	0.026	0.022	0.016	0.154
Period_dummy	-0.807	0.928	-1.540	0.866
Constant	-1.469	0.823	0.065	0.992
Change in real median income				
Lag_Δ_Income			0.076	0.590
Δ_Infrastructure	0.610	0.000	0.430	0.009
Δ_Population	0.137	0.033	0.157	0.015
log_Income_1996 – 1996-01 coeff	2.031	0.572	2.504	0.498
log_Income_2001 – 2001-06 coeff	-3.500	0.535	-4.867	0.400
%_Unemployed_1996 – 1996-01 coeff	0.004	0.981	-0.019	0.915
%_Unemployed_1996 2001-06 coeff	-0.196	0.516	-0.224	0.473
Period_dummy	60.755	0.169	78.865	0.081
Constant	-19.830	0.592	-23.388	0.538
Inter census change in usually resident population				
Δ_Infrastructure	0.519	0.000	0.515	0.000
Δ_Overseas_Born	0.414	0.000	0.412	0.000
Industry_Mix	0.474	0.000	0.490	0.000
log_Income_1996 – 1996-01 coeff	5.284	0.122	5.440	0.109
log_Income_2001 – 2001-06 coeff	18.403	0.000	18.411	0.000
%_Unemployed_1996 – 1996-01 coeff	0.224	0.170	0.217	0.183
%_Unemployed_1996 2001-06 coeff	0.852	0.002	0.846	0.002
Period_dummy	-136.599	0.001	-135.114	0.001
Constant	-60.335	0.084	-61.764	0.075
Change in estimated real land value				
Lag_Δ_Landvalue			0.064	0.579
Δ_Infrastructure	4.140	0.003	2.179	0.125
Log_Landvalue_1996, 1996-01 coeff	1.024	0.900	-0.498	0.953
Log_Landvalue_1996, 2001-06 coeff	-34.788	0.002	-37.416	0.002
Δ_Population	-0.020	0.984	0.426	0.677
Period_dummy	470.428	0.000	477.405	0.000
Constant	-29.593	0.743	0.539	0.995

NB: Grey shading indicates significance at 5 percent level

Figure 1 The Roback model with endogenous local authority spending

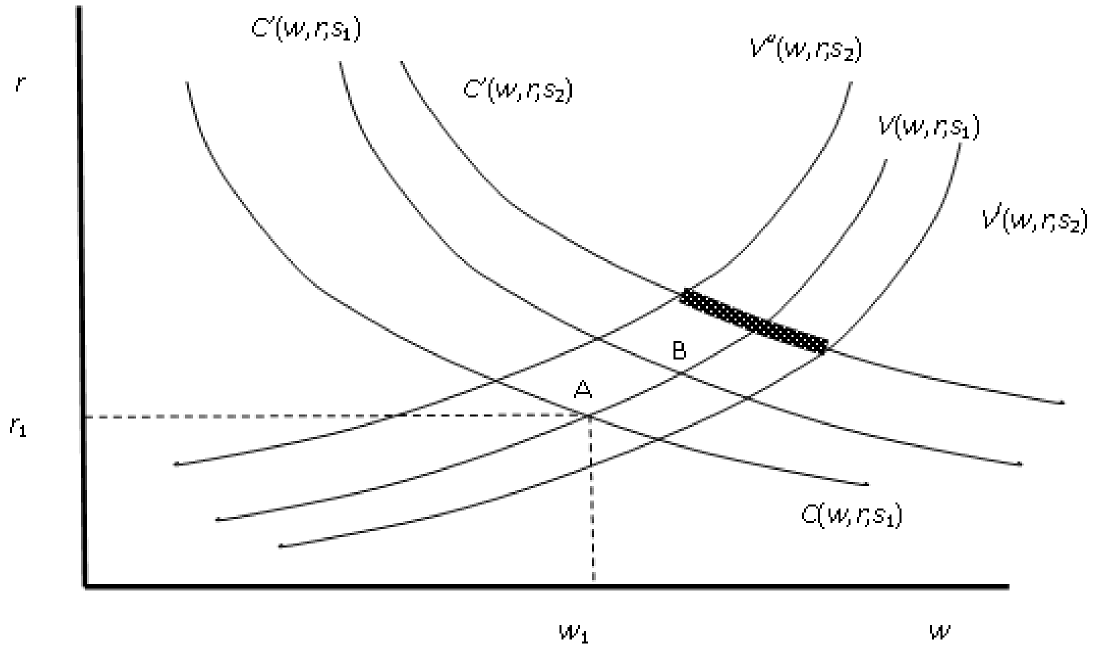


Figure 2 New Zealand Labour Market Areas

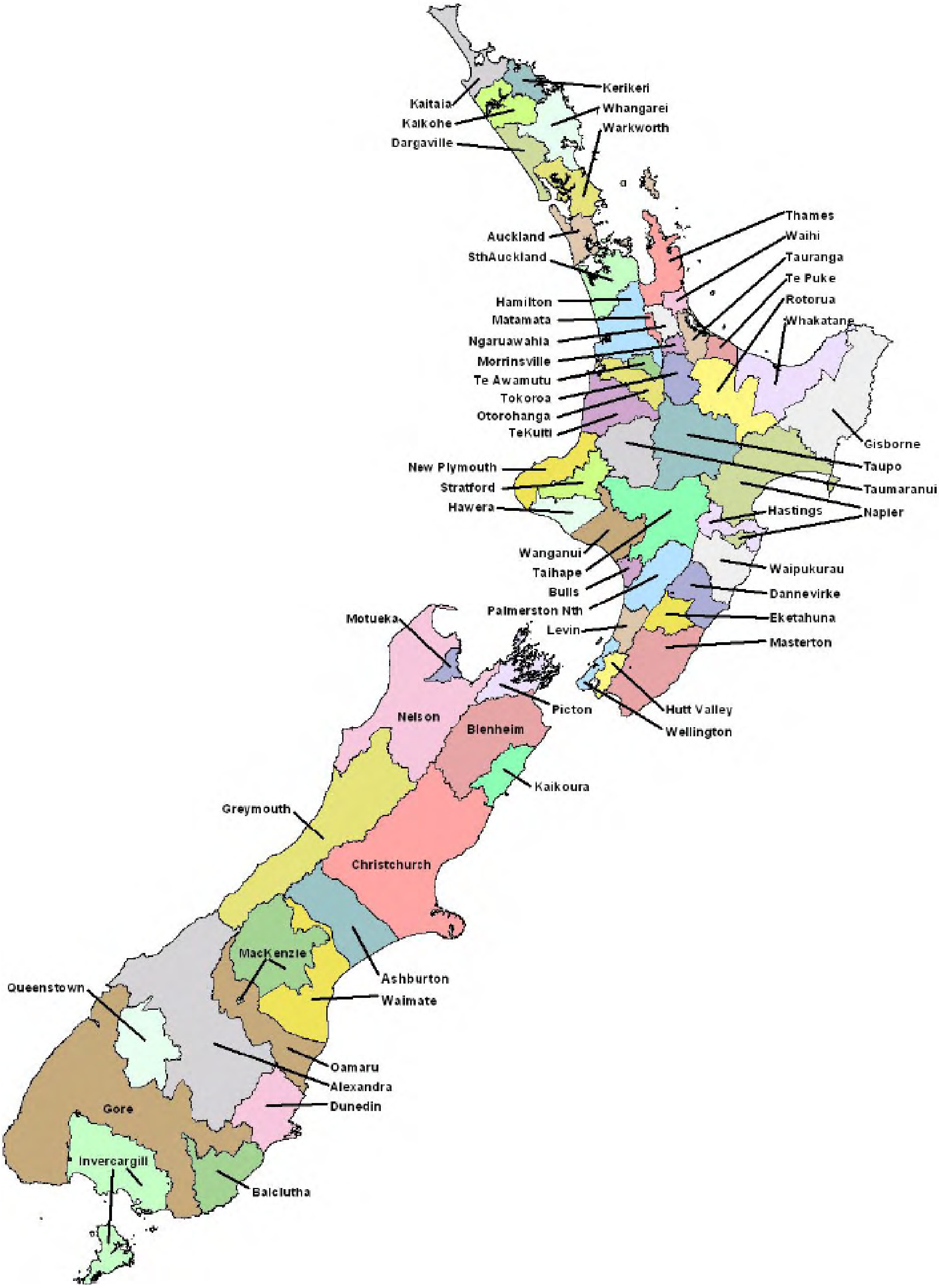
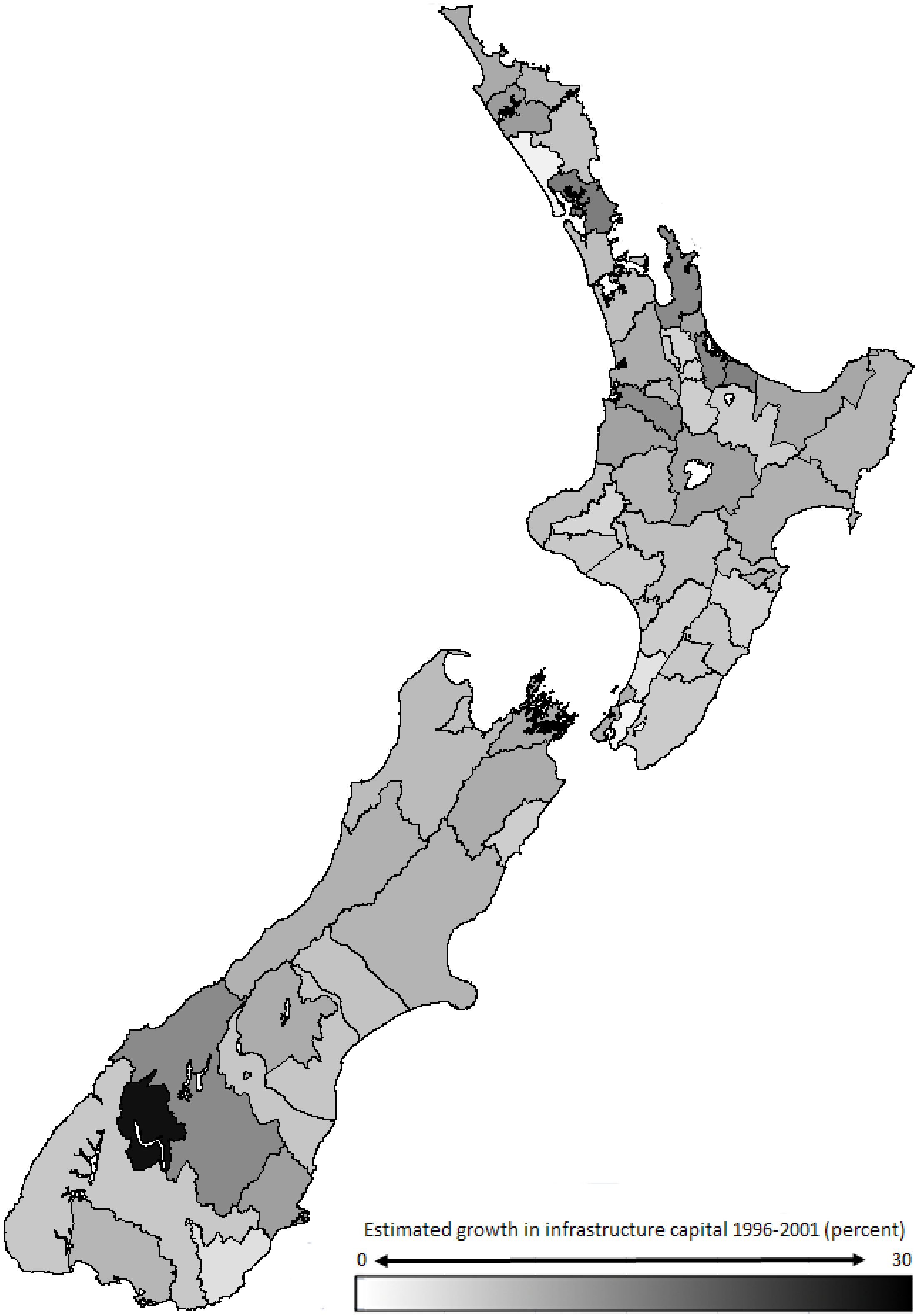


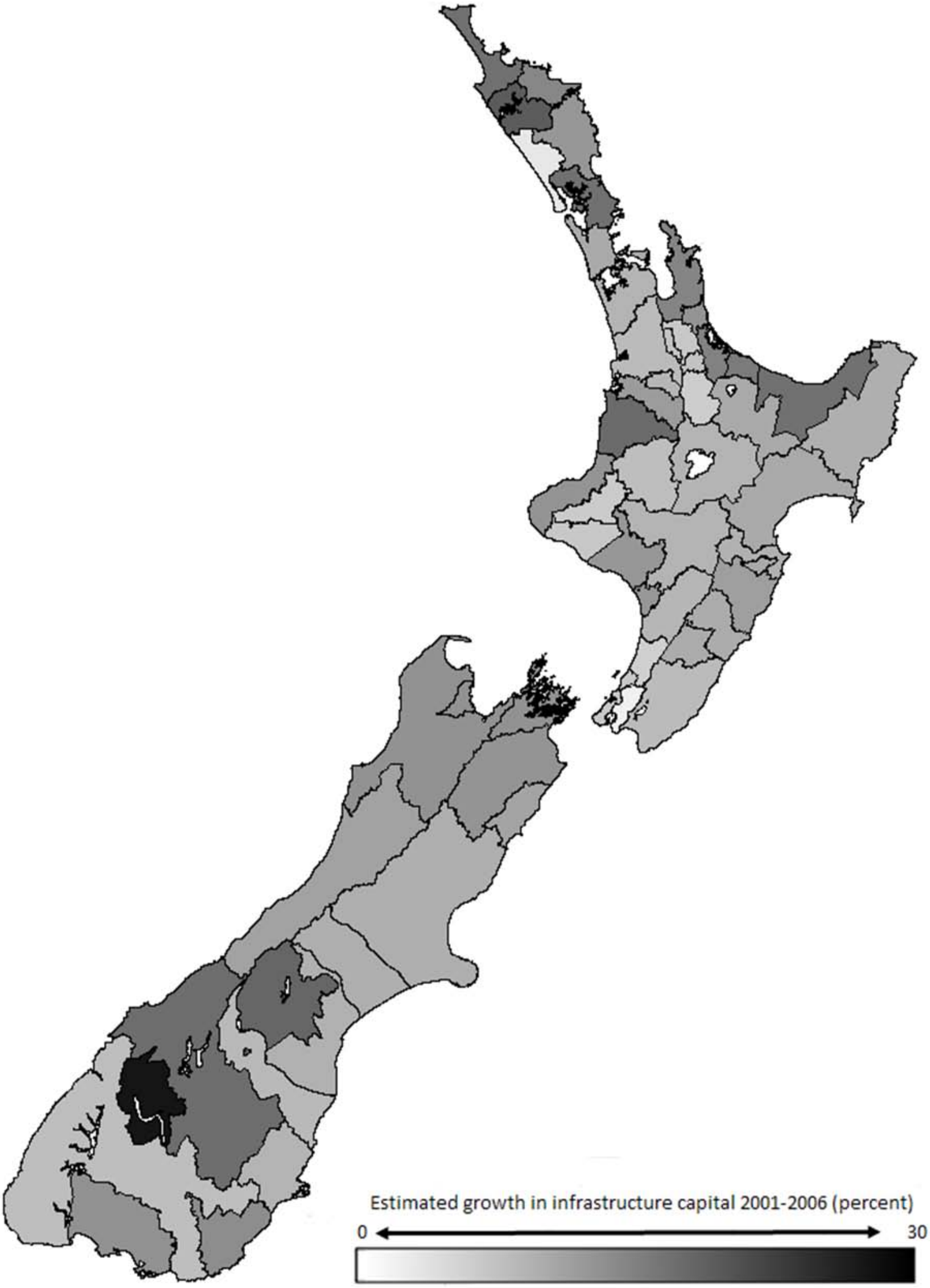
Figure 3 Estimated growth in infrastructure capital 1996-2001



Morans I

I	E(I)	sd(I)	z	p-value*
0.156	-0.018	0.078	2.239	0.013

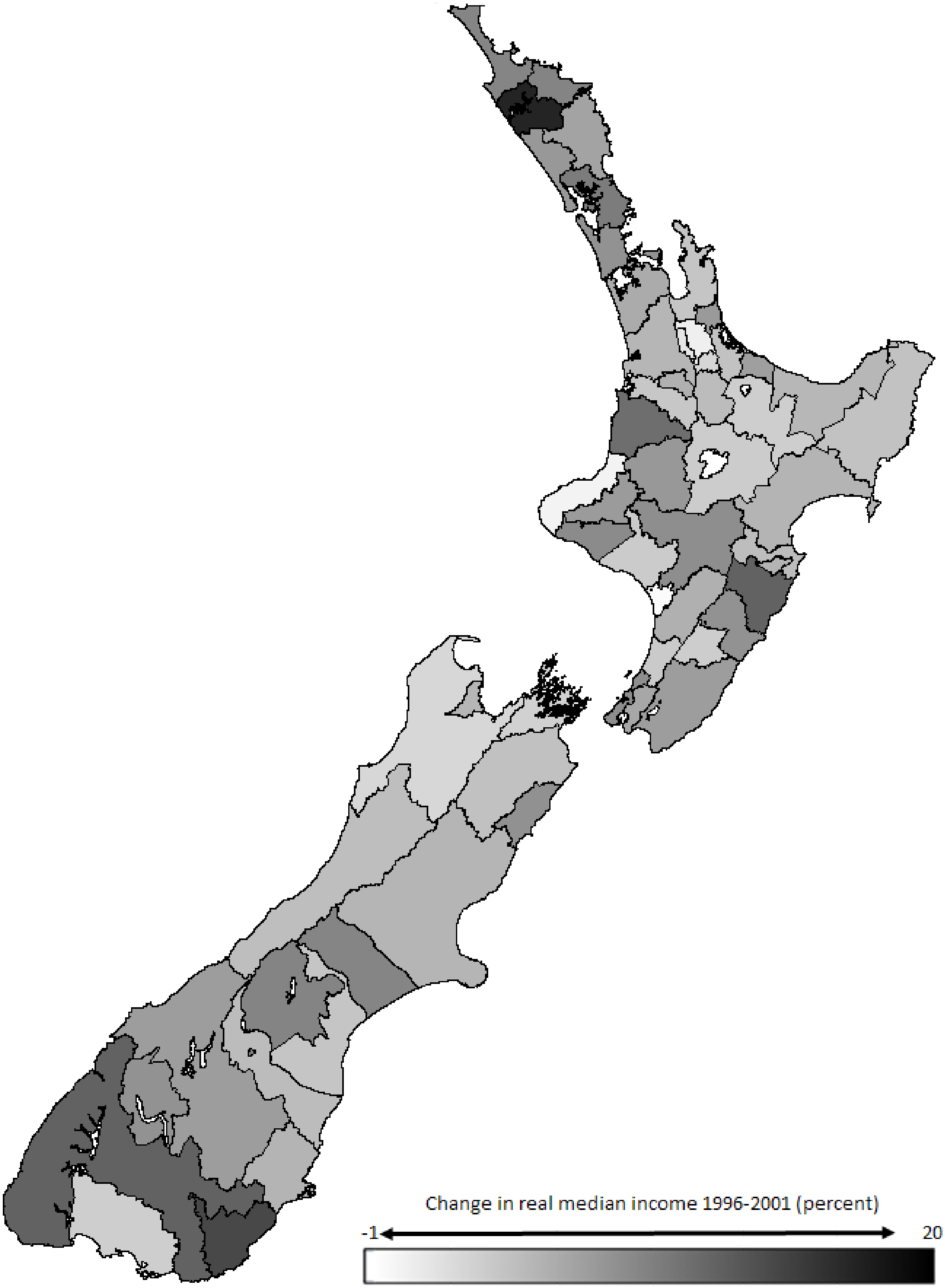
Figure 4 Estimated growth in infrastructure capital 2001-2006



Morans I

I	E(I)	sd(I)	z	p-value*
0.227	-0.018	0.083	2.955	0.002

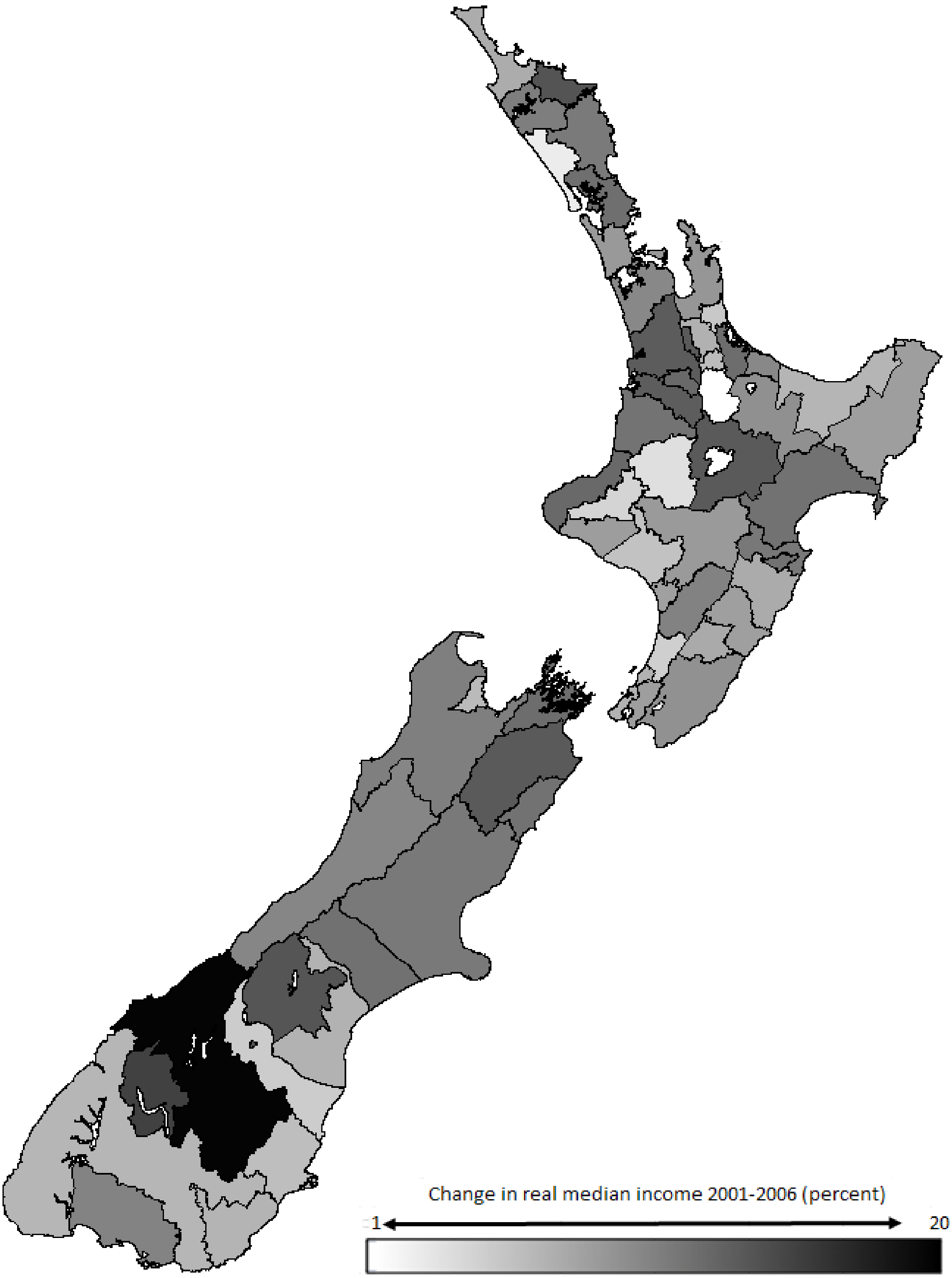
Figure 5 **Change in real median income 1996-2001 (percent)**



Morans I

I	E(I)	sd(I)	z	p-value*
0.168	-0.018	0.084	2.206	0.014

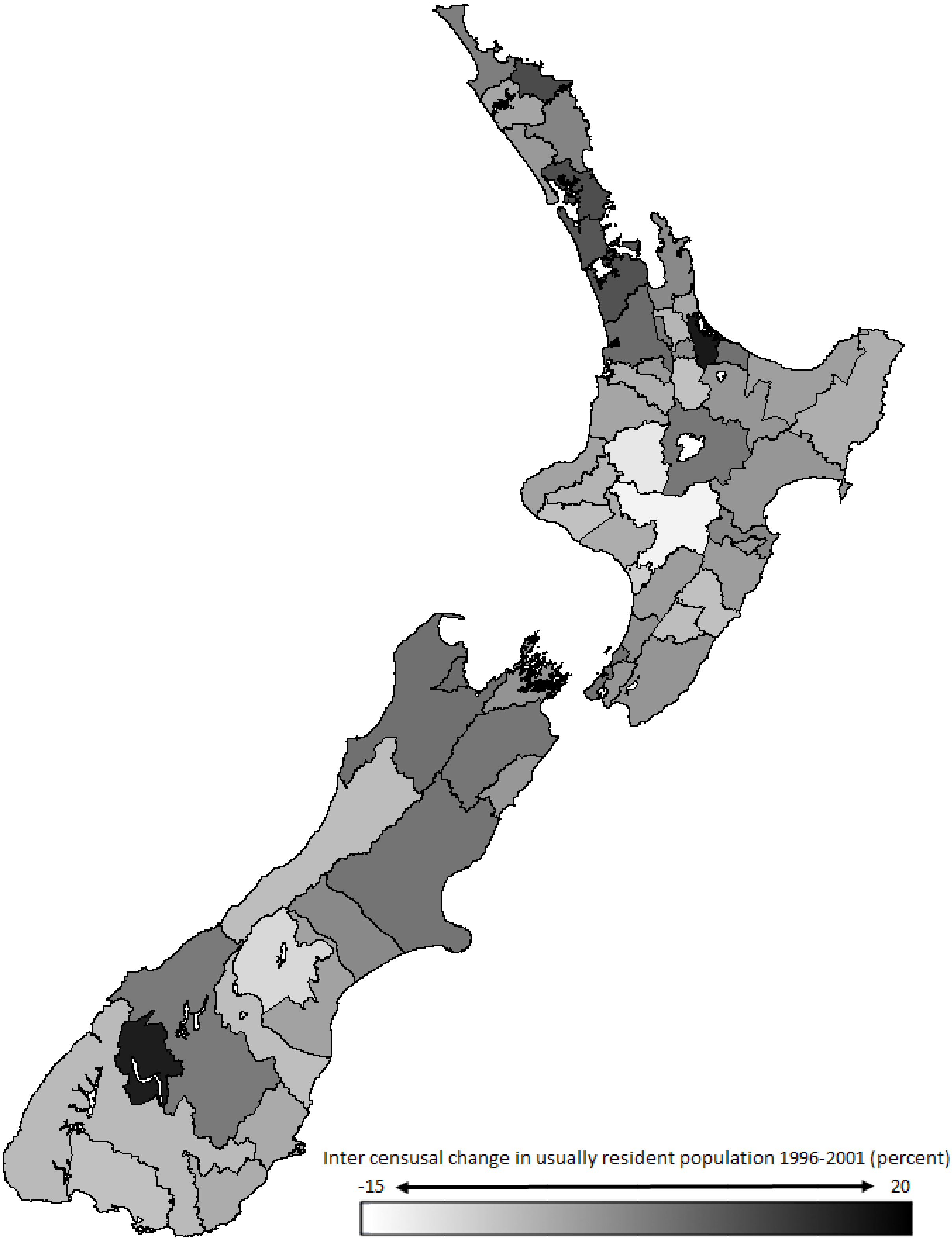
Figure 6 Change in real median income 2001-2006 (percent)



Morans I

I	E(I)	sd(I)	z	p-value*
0.079	-0.018	0.084	1.144	0.126

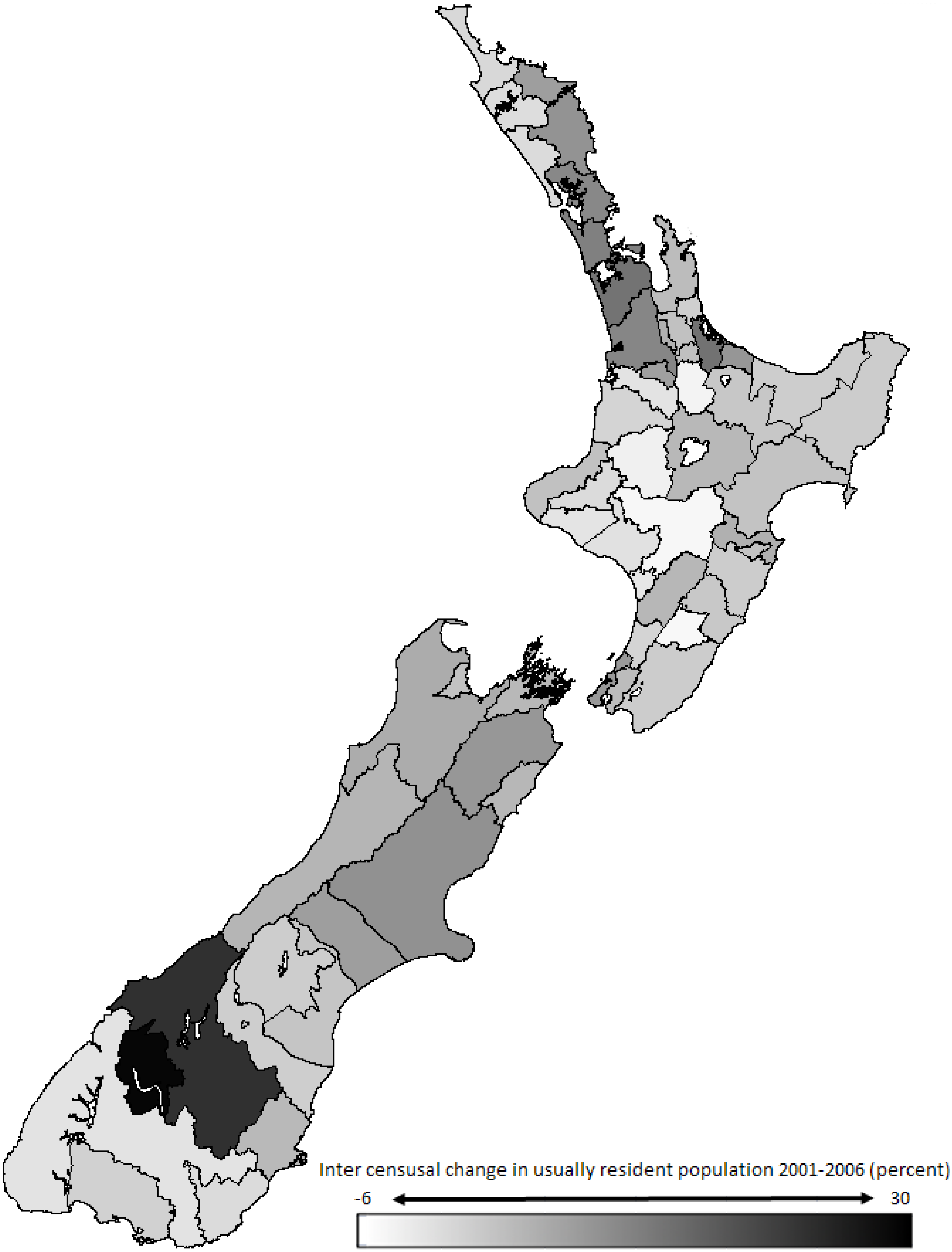
Figure 7 Inter censusal change in usually resident population 1996-2001 (percent)



Morans I

I	E(I)	sd(I)	z	p-value*
0.212	-0.018	0.084	2.732	0.003

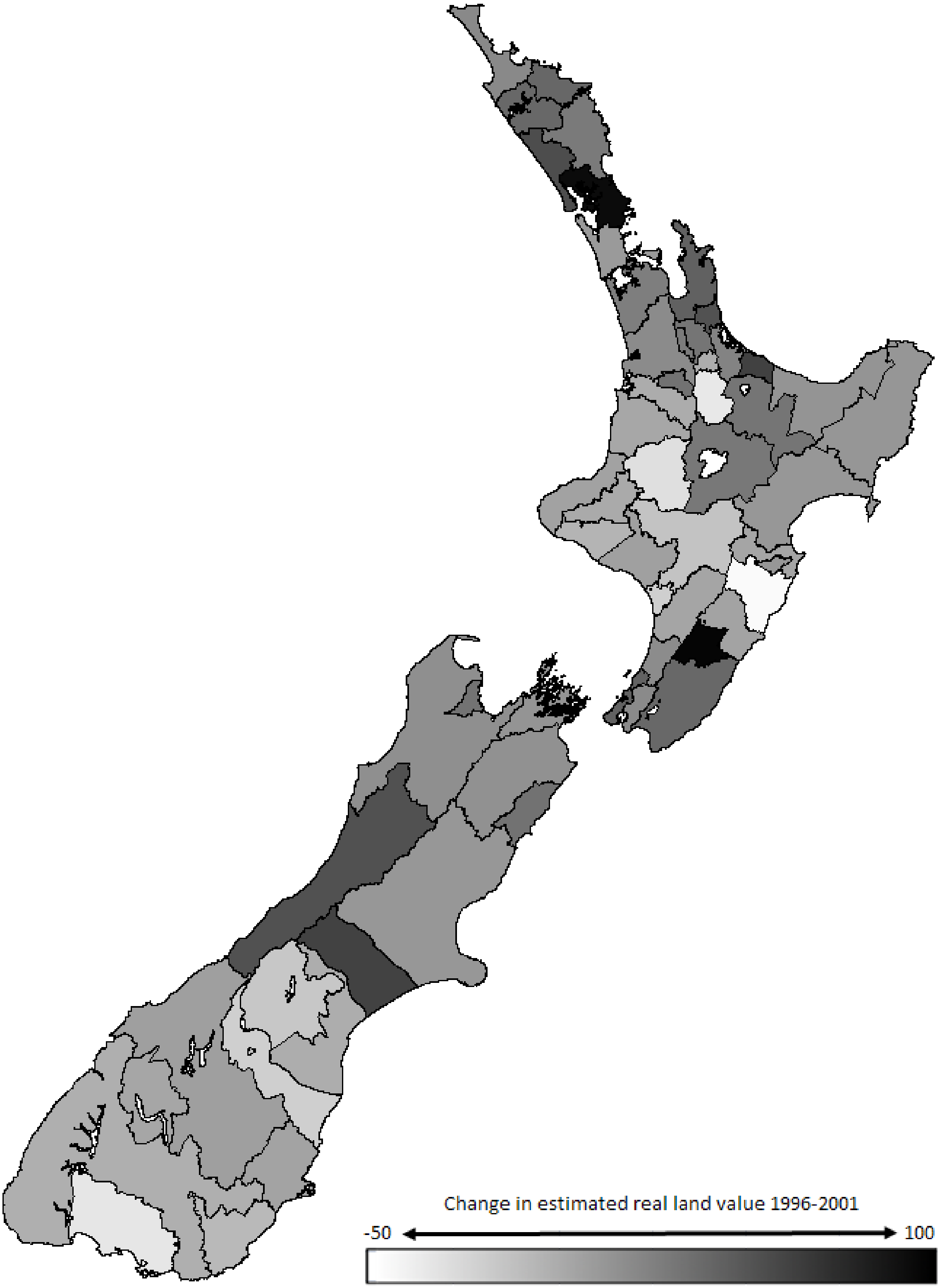
Figure 8 Inter censusal change in usually resident population 2001-2006 (percent)



Morans I

I	E(I)	sd(I)	z	p-value*
0.253	-0.018	0.081	3.316	0.000

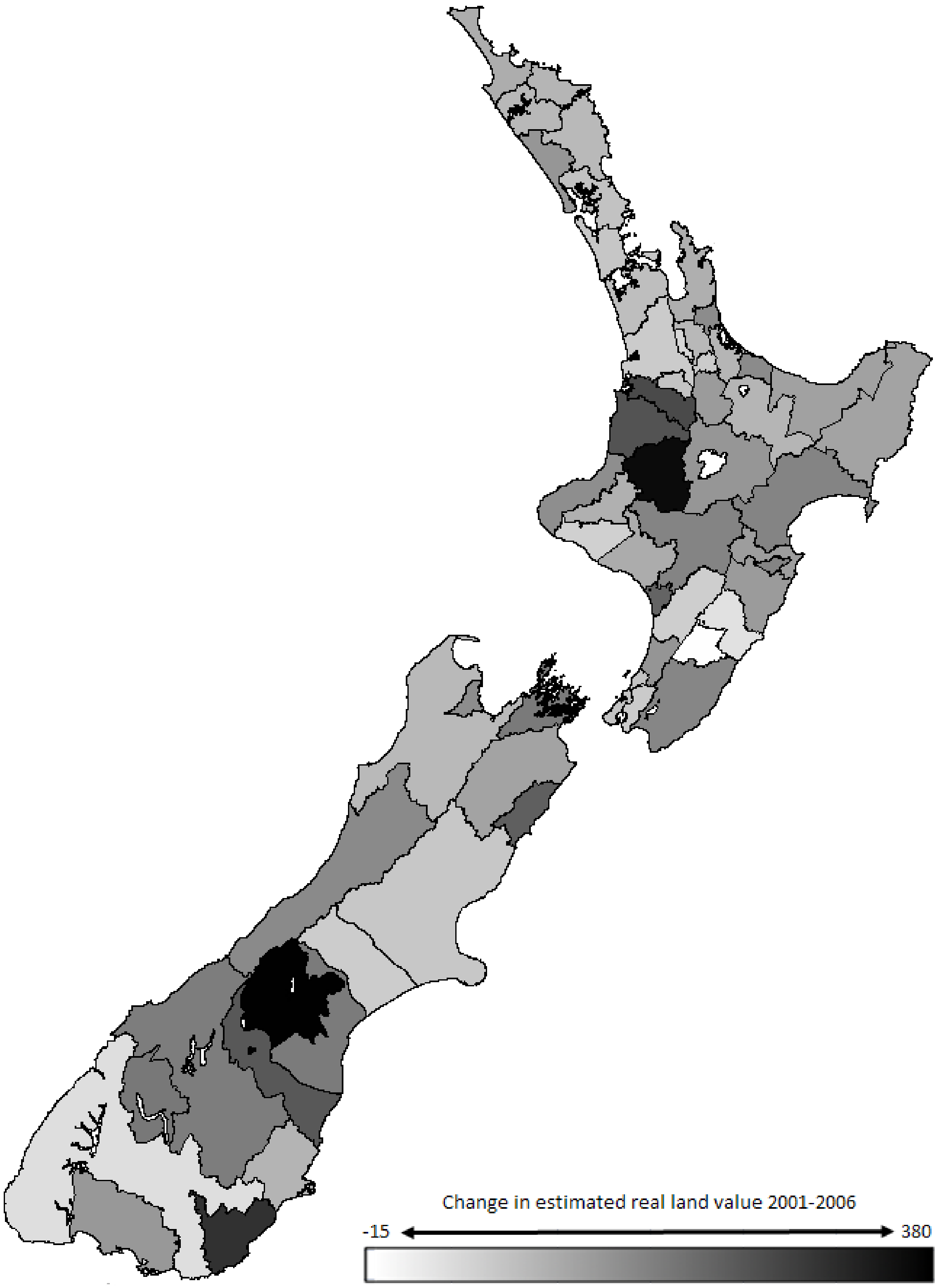
Figure 9 Change in estimated real land value 1996-2001



Morans I

I	E(I)	sd(I)	z	p-value*
0.200	-0.018	0.084	2.583	0.005

Figure 10 Change in estimated real land value 2001-2006



Morans I

I	E(I)	sd(I)	z	p-value*
0.129	-0.018	0.084	1.750	0.040

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