Infrastructure's Long-Lived Impact on Urban Development: Theory and Empirics

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Abstract
We analyse impacts that infrastructure provision and other factors have on long run urban growth. Reflecting spatial equilibrium insights, growing cities have preferred attributes relative to other cities. These attributes may include natural characteristics, social amenities and transport infrastructure that have productive and/or amenity value. We outline a theoretical model that includes distance-related effects on individual utility and thence population location, and we test this model using historical data covering 1926 to 2006 across 56 New Zealand towns. Instruments dating back to 1880 are used to deal with potential endogeneity issues, and we use spatial-econometrics techniques to test for spatial spillovers between cities. Our analysis shows that four dominant factors have impacted positively on urban growth, especially since 1966: nearby land-use capability, human capital, sunshine hours and proximity to the country's dominant city, Auckland.

JEL codes
H54, R12

Keywords
Infrastructure, city development, population growth, migration, spatial equilibrium

Contents

1. Introduction

What effects do infrastructure investments and other factors have on long term urban development? We address this question using a newly specified theoretical model and using data covering 80 years across 56 New Zealand towns.[1] The analysis helps policy-makers and researchers to understand the intended, and potentially unintended, long run consequences of their infrastructure investment decisions.

Reflecting spatial equilibrium insights (Overman et al, 2010; Grimes, 2014), we maintain that population flows reflect people's overall assessments of urban areas. Through revealed preference, growing cities are shown to have preferred attributes (wages and amenities combined, adjusted for costs) relative to other cities. Social infrastructure (such as higher educational institutions and hospitals) and transport infrastructure may have both productive and amenity value. Thus increased provision of such infrastructure within a city may enhance a city's attractiveness provided that the benefits of the new infrastructure exceed local costs of provision. Agglomeration benefits may magnify the benefits of infrastructure investments, especially in larger cities. Poor infrastructure provision linking an urban area to major cities and other amenities may, conversely, reduce the attractiveness of that urban area, curtailing its long run population growth. In the next section, we summarise insights gained from prior studies about the effects of infrastructure investments on city development. Two specific areas are highlighted –transport infrastructure and higher educational institutions (HEIs) – to illustrate effects of infrastructure assets that have differing mixes of productive and amenity value.

We then outline a theoretical model that includes distance-related effects on individual utility, incomes and costs. Ceteris paribus, people favour living close to amenities, and they earn higher wages when they are located in or near a major agglomeration. Enjoyment of amenities declines as distance to those amenities increases, and wages decline as distance from the major agglomeration increases. Transport costs increase as distance to these assets increases. Each of these factors influences urban population growth. The model is related to that in a recent paper by Duranton and Turner (2012). However, the new specification avoids a convenient but questionable assumption in their approach in relation to the effect of distance on individual utility.

[1] The digitisation of all Statistics New Zealand Yearbooks has been of invaluable assistance in the derivation of long term data for this analysis. All digitised Yearbooks are available at: http://www.stats.govt.nz/browse_for_stats/snapshots-of-nz/digital-yearbook-collection.aspx.

We test our model using a newly derived long-term (80 year) historical series on urban populations measured every 10 years from 1926 to 2006 for 56 towns across New Zealand. This dataset enables us to relate population growth of these urban areas to infrastructure provision. We include tests of the impacts of several social and transport infrastructure variables. Non-infrastructure control variables include climatic variables, land-use capability, regional variables and a human capital measure.

The empirical analysis shows that four dominant factors have impacted positively on urban growth, especially since 1966: land-use capability, human capital, sunshine hours and proximity to the country's dominant city, Auckland. In our concluding section, we interpret how these results may usefully influence the formulation and implementation of infrastructure policy.

2. Prior Literature

2.1. Infrastructure and Population Growth

Models of spatial equilibrium demonstrate how population flows across regions in order to equate utility in different areas (Glaeser and Gottlieb, 2009; Overman et al, 2010; McCann, 2013). In these models, individual utility is derived from consumption of amenities plus private consumption of tradable and non-tradable goods (where the price of the former is exogenous to the region and that of the latter is endogenous). Consumption is restricted by the individual's budget constraint where wages may be city-specific, reflecting agglomeration and other factors.

Grimes (2014) extends the Overman et al model to include infrastructure provision, deriving the conditions under which a new infrastructure investment within a city will expand that city's population. To do so, the infrastructure investment must raise amenity-adjusted real wages, where amenity-adjusted wages include the value of unpriced amenities to an individual. An infrastructure investment may increase amenity-adjusted wages through a variety of mechanisms: first, the infrastructure may raise amenities in a city (e.g. through provision of a new concert hall); second, the infrastructure may reduce travel costs (e.g. through provision of an improved transport network); third, the infrastructure may raise productivity and hence wages (e.g. through a new port or airport); fourth, the infrastructure may raise skills and hence wages (e.g. through provision of a higher educational institution). However, the new infrastructure may result in cost increases, for instance through higher taxes to pay for the new facilities and through higher land costs (house prices) as new population is attracted to the city. The latter effect, which occurs as a result of net inward migration in response to the new investment, is the mechanism by which the spatial adjustment to the new infrastructure is equilibrated.

Empirical applications of the spatial equilibrium approach can be separated into those that deal with localised infrastructure (within a locality) and those that deal with infrastructure connecting cities. An example of the former is the study by Duflo and Pande (2007) of the localised impact of the construction of dams in India. An example of the latter is the study by Coleman (2012) of the effect of the construction of the Erie Canal on economic activity in rural areas of New York State. Another example is that of Gibbons et al (2012) who examine the effects of new inter-city road infrastructure on firm outcomes in the UK. Each of these studies uses an exogenous event (construction of a dam, canal or inter-city road) to examine economic outcomes. Where such an event is not available, careful testing has to be undertaken to ensure that the infrastructure that is the subject of study is not an endogenous response to population growth. Where it may be an endogenous response, the use of exogenous instruments in estimation (as in Wu and Gopinath, 2008) is required.

2.2. Transport Infrastructure and Regional Growth[2]

Early studies which find positive impacts of transport infrastructure on economic growth include Mera (1973) for Japan's regions, Blum (1982) for regional growth in West Germany, and Aschauer (1989) and Munnell (1990) for regions within the United States. Economic growth induced by transport investments encourages employment and population growth as consumers move across regions to maximise wages. Thus transport investments result in population growth and employment growth within regions where imperfect, spatially competitive labour markets lead to the provision of higher net wages (Fujita and Thisse, 2002).

Population changes within metropolitan areas and employment growth across metropolitan areas have been the focus of more recent analyses of the role that the United States interstate highway system has played in the development of cities (Baum-Snow, 2010; Duranton and Turner, 2012). Both studies estimate the effect of state highway infrastructure on regional population growth and share the same main instrumental variable, the 1947 plan of the US interstate highway system to account for the potential endogeneity of the highway network.[3] However, the foci of the investigations differ. Duranton and Turner explore the long term effect of transport infrastructure on regional population growth, whereas Baum-Snow examines its impact on within-city population decentralisation. Baum-Snow finds that highways lead to people residing within suburban areas rather than within the central city, and that declining city transport costs as a result of road construction has led to firm productivity gains, resulting in

[2] Lutchman (2013) provides an in-depth discussion of the relevant literature.

[3] Duranton and Turner argue that instrumental variables for road and highway networks must also control for historical population since historical population levels affect future population growth independently from highway infrastructure.

higher wages for workers. Duranton and Turner's analysis finds that a 10% increase in a given city's stock of interstate highways leads to a 1.5% increase in employment over 20 years.

Using similar instruments, Duranton et al (2013) find that the quality of the highway network affects the structure of a city's production, with a 10% increase in a city's highways leading to a 5% increase in tonnes of goods exported by that city. This result mirrors earlier results on the importance of the transportation network for city production structures (Fernald, 1999). Similarly, the quality of the transportation network may affect the degree of agglomeration economies within and surrounding a city (Fujita and Thisse, 2002; McCann, 2013; Maré and Graham, 2013). However, improved transportation links do not necessarily lead to agglomeration for all sectors. Glaeser (1998) suggests that declining transport costs within the United States led to fewer jobs within the manufacturing sector within cities that have high urban densities, while Behrens and Picard (2011) find that freight rate differentials can incentivise manufacturing firms to scatter across space instead of clustering. Service sectors benefit from falling transport costs through the benefits of clustering, and thus choose to locate within cities. In their study of the distance decay of agglomeration benefits, Graham et al (2009) conclude that both the distance decay and productivity impacts of agglomeration are greater for firms in services than for those in manufacturing.

Beyond its contribution to production, transport infrastructure has value by reducing costs for consumers who reside within close proximity to it. If consumers or firms prefer to locate within close proximity to these interchanges, their demand will be reflected in the increased price of housing or commercial buildings in the immediate area (Haughwout, 2002). Transport corridors that are able to deliver both mobility and amenity improvements have been found to deliver improved economic outcomes reflected in increased land rents (Donovan and Munro, 2013; Grimes and Liang, 2010, Grimes and Young, 2013).

One issue in modelling the impacts of transport infrastructure is the potential need to take into account spatial spillovers. Evidence for the existence of regional spillovers related to transport infrastructure is mixed and may depend on the definition and size of 'regions'. Neither Holtz-Eakin and Schwartz (1995) nor Duranton and Turner (2012) finds statistically significant spillover effects of highways across regions in the United States. By contrast, a general method of moments (GMM) estimate of a dynamic regional production function that includes the spillover effects of highways in US states finds that neighbouring states acquire some of the productivity benefits of highway improvements carried out in a nearby state (Jiwattanakulpaisarn et al, 2011). Similarly, within China, Yu et al (2013) find that land transport investment in neighbouring regions has a significant spillover effect across regions but the magnitude of the effect differs depending on the current productivity of the regional economy. Ding (2013) supports these propositions with analysis of the positive spillover effects associated with urban roads and regional roads for Chinese regions.

Of the above studies, Duranton and Turner's investigation of transport infrastructure and regional growth is the most similar to ours. Their model specification originates directly from consumer theory, with the inclusion of variables for distance travelled and exogenous amenities within a city in the representative resident's utility function. This approach yields equations for three variables: the rate of change of population, investment in roads, and initial road characteristics. Population change is a function of the prior period's level of population and roading, plus observable time-invariant regional characteristics. Investment in roads is a function of the same variables while initial road characteristics are a function of the prior population level, observable time-invariant regional characteristics and a vector of exogenous (historical) regional characteristics. However, Duranton and Turner's postulated consumer utility function treats distance travelled by an individual as contributing positively to consumer utility which contrasts with the notion that travel is a cost. Our theoretical approach uses that of Duranton and Turner as a starting point but instead treats distance travelled as a negative contribution to utility in keeping with the more standard treatment of distance as a cost.

2.3. Higher Educational Institutions, Skills and Regional Growth[4]

The impact of Higher Education Institutions (HEIs) on regional growth can be interpreted within the context of endogenous growth models which relate long term growth to endogenous investments in physical, knowledge, and human capital (Romer, 1990; Lucas, 1988). Investments in human capital and new knowledge by firms and HEIs are considered to result in knowledge spillovers, resulting in a positive externality benefiting the local economy, and possibly spilling over to other regional economies. These models allow for the possibility of sustained permanent growth rate differences across regional economies resulting from differences in innovative efforts and capabilities, with new knowledge being subject to increasing returns to scale.

HEIs may be modelled as an input into the knowledge production function (Griliches, 1979 and 1984) which relates innovative outputs, such as patent applications, to innovative inputs such as research and development (R&D) and human capital. Jaffe (1989) analyses the potential importance of geographically based complementarities between university and firm

[4] Apatov (2013) provides an in-depth discussion of the relevant literature.

research within the local area, finding that where such complementarities exist, universities are a catalyst for increasing innovation output at the regional level.

Jacobs (1969) argues that knowledge can be divided into two main classifications: codified knowledge and tacit knowledge. Codified knowledge is knowledge that has a common interpretation and can be cheaply transferred across agents and space. Conversely, tacit knowledge is costly to transfer across agents and space, requiring proximity (face to face interaction) in order to be absorbed. If much of the newly generated knowledge is tacit, the spillovers will be geographically bounded with benefits decreasing across space. This means that firms closer to the source of the new knowledge will be better able to absorb it, incentivising firms and people to locate in the area. Furthermore, if innovation grows disproportionately with size (Baumol, 2002), then a feedback mechanism between clustering and innovation may occur, similar to the process suggested by Krugman (1991).

Proximity to the primary knowledge source may be insufficient to generate benefits from knowledge production; the region's capabilities to absorb and apply the knowledge may also be critical (Fagerberg, 1987). For example, two regions which increase their local innovative efforts (or that are similarly proximate to new sources of knowledge) may experience significantly different economic growth outcomes if they differ in their ability to extract externally generated knowledge in order to give these ideas economic value. Thus the quality of local human capital may be crucial in generating long term economic benefits from new knowledge. Glaeser et al (1995) examined population growth patterns for over 200 US cities over 1950 to 1990. In testing the importance of a number of initial conditions that included ethnic structure, labour force and educational indicators (plus geographic dummies) the study found that initial education levels of the population were an important determinant for cities' productivity, positively affecting growth in income, employment, and population.

Duch et al (2011) analysed the channels by which universities contribute to regional growth in Spain (through human capital creation, knowledge generation, and technology transfer). Under all specifications, initial conditions – the share of tertiary educated workforce and the initial stock of patents – were found to have positive and significant growth effects. In contrast, other channels for a university's contribution (university R&D expenditure, R&D incomes, and university internships) were found to be insignificant. Similarly, Trendle et al (2004), applying a spatial lag model to Queensland, found that the proportion of population with a vocational, bachelor or higher degree is an important determinant for local incomes. Wang (2010) found that HEIs contribute to local area growth through their production of skilled graduates, albeit with heterogeneity in effects according to the institution's size, disciplines offered and level of graduates (with business degrees and Masters/Doctoral qualifications having a greater effect). Furthermore, application of a spatial framework showed that such benefits were not limited to the host county, but also positively affected neighbouring counties' employment growth rates. Anderson and Karlson (2005) found that such positive spillover effects extended (in Sweden) to the intra-municipal and intra-regional levels, but not to extra-regional levels, consistent with the localised importance of tacit knowledge.

A common empirical functional specification for the studies cited above is the change-level approach. In this specification, growth rates for the outcome variable of interest (e.g. population, economic activity or incomes) are a function of the levels of pre-existing characteristics (e.g. skills, or stocks of knowledge). While coming from a different theoretical basis, this functional form is essentially the same as that arrived at by Duranton and Turner (2012), and is the functional form that underlies our analysis.

In applying this type of framework, Crescenzi (2005) showed that while R&D investment has a positive and significant effect for a region, innovative efforts will have a better return in regions that are on average more educated and accessible. Sterlacchini (2008) similarly found that local R&D investment was positively associated with economic growth for richer regions but not for poorer regions, whereas an increase in the tertiary educated population share was positive and significant for both types of regions. Rodriguez-Pose and Crescenzi (2008) also find that differences in the education level of the workforce and accessibility to other regions are important factors in translating these investments into economic growth. Thus both distance from the source and skill levels are important complements in gaining benefits from the generation of knowledge.

Mollick and Mora (2012) recognise the potential two-way causation between education levels and growth. To avoid bias, they use a two equation system for growth in population and education level (share of tertiary educated workforce) in the initial period of the analysis. Their study again supports the importance of a tertiary educated workforce for population and employment growth, and note that when estimation does not account for endogeneity, the coefficients understate the importance of education for growth.[5]

These studies together suggest that the presence of HEIs assists local growth, but that a key channel of such influence may be through the production of an educated workforce rather than through the direct contribution of an HEI to knowledge production. This latter channel

[5] This finding may imply that HEIs have been explicitly located in otherwise underperforming areas.

may, however, be dependent on other complementarities such as the relationship with local industry R&D.

In the New Zealand context, Apatov (2013) found that if potential endogeneity in the location of HEIs (universities and polytechnics) is not controlled for, HEIs are found to have a positive link with local population and employment growth. In addition, this growth effect was found to increase in a non-linear manner with increasing levels of population density. However, after controlling for potential endogeneity in HEI location - by instrumenting using population estimates from 60 years earlier - the relationship is insignificant in almost all specifications. In keeping with a number of international studies, however, the share of tertiary qualified working age population in an area is found to be a key driver of economic growth.

2.4. Amenities and Regional Growth

Desmet & Rossi-Hansberg (2013) adapt the Alonso-Mills-Muth model of city structure (Alonso, 1964; Mills, 1967; Muth, 1969; Kulish et al, 2012) to examine the determinants of city size in the US and China. In their theoretical model, an increase in each of city productivity, city efficiency (e.g. of public services) and city amenities leads to an increase in city size. Conceptually, this approach is consistent with the model of Overman et al (2010) in which people migrate between cities to take advantage of higher amenity-adjusted real wages. Desmet & Rossi-Hansberg find strong empirical support for their model, with city amenities playing a particularly important role in determining city size. An important feature of their model is the role played by the retired population. Retirees are found to shift to cities that have high amenities even where those cities are not highly productive.

In considering amenities that affect people's residential locations, Desmet & Rossi-Hansberg build on prior studies that demonstrate the importance of weather (especially winter and summer temperatures, and precipitation) and coastal locations for determining people's location decisions within the US (Rappaport, 2007, 2008 and 2009; Rappaport and Sachs, 2003). These studies' findings regarding the importance of weather for attracting population mirror an earlier finding by Glaeser et al (2001) in this respect. In that study, Glaeser et al describe four critical urban amenities. The first is a rich variety of services and consumer goods including "restaurants, theaters and an attractive mix of social partners". Larger cities tend to excel in these respects. The second is aesthetics and physical setting, including weather. The third is good public services and the fourth is speed or connectivity. Each of these factors should therefore be included either directly or indirectly in an empirical model explaining long run population growth.

Indeed, Glaeser et al (2001) and Glaeser and Kohlhase (2004) argue that the importance of amenities in explaining population growth has been increasing over time. According to this argument, improvements in transport technology have eliminated the need for cities to be tied to natural resources or natural transport hubs, while rising real incomes have increased demand for amenities . Moreover, as noted by Duranton and Puga (2013), the growth of the retired population is likely to have added to the advantages of amenity-rich cities in Western countries.

3. Theory of Population Location

In order to assess the impacts of the above factors on population location, we outline a simple encompassing model. We assume that individual *i* has utility defined over private consumption, C_i (≥0), plus consumption of unpriced natural and social amenities available at the location at which the individual lives, X_i (≥0),[6] and consumption of amenities available at a core metropolitan location, M_i (≥0). For simplicity, we assume a Cobb-Douglas functional form so that the individual's utility function is represented by (1):

$$U_i = C_i^{\beta_i} M_i^{\gamma_i} X_i^{\alpha_i} \tag{1}$$

where: $\beta_i, \gamma_i, \alpha_i, > 0$. Utility derived from metropolitan amenities is a function of the quality of those amenities (Q) and of the individual's proximity ($P_i \geq 0$) to the core city. For example, proximity to a social amenity such as a base hospital may confer greater utility through peace of mind than being distant from the hospital.[7] An increase in P_i denotes that the individual is located closer to the core city, and $P_i = 0$ denotes that the individual is located in a peripheral location, i.e. a location that is at the furthest distance from the core city. We further assume that $M_i = P_i^{\delta_i Q/\gamma_i}$ so that an increase in either proximity to the core city or in the quality of amenities, ceteris paribus, increases the individual's effective consumption of core city amenities. Hence the individual's utility function can be rewritten as (2):

$$U_i = C_i^{\beta_i} P_i^{\delta_i Q} X_i^{\alpha_i} \tag{2}$$

[6] For simplicity, we treat these characteristics as a scalar in this derivation, but the analysis is easily extended to a vector of local characteristics.

[7] Duranton and Turner's (2012) utility function accords distance travelled a positive elasticity, based on an argument that people travel in order to experience amenity services. By contrast, we consider that additional distance from the core city's amenities (i.e. lower proximity to the core city) reduces utility.

The individual chooses each of P_i and X_i through their choice of location. Thus we utilise a monocentric model modified by each locality having its own distinctive natural and social amenities.[8]

The individual's budget constraint comprises her earnings, W_i, less expenditure on consumption C_i, (with the consumption price normalised to unity), land L_i, and transport costs T_i. Thus:

$$W_i = C_i + L_i + T_i \tag{3}$$

The wage rate for individual i is set at what the individual could earn in the periphery (i.e at $P_i = 0$), w_i, plus an individual-specific proximity-related premium (at rate q_i) reflecting productivity gains as the individual locates to a less peripheral area, plus an individual-specific productivity-related premium (at rate s_i) associated with the characteristics of the individual's chosen locality. Assuming a linear function, we therefore have:

$$W_i = w_i + q_i P_i + s_i X_i \tag{4}$$

Land costs at the periphery are given by $L_i = l$. They increase with proximity to the core location at rate p (which is identical for all individuals), and they are also positively related to local characteristics that raise local amenity values (with parameter x). Thus:

$$L_i = l + pP_i + xX_i \tag{5}$$

Expenditure on transport is an individual-specific decreasing function of proximity to the core, with transport costs $T_i = t_i$ at $P_i = 0$, decreasing at rate r_i as proximity to the core rises. Hence:

$$T_i = t_i - r_i P_i \tag{6}$$

Each of q_i, s_i, $p, x, r_i > 0$. Substituting (4) - (6) into (3), and denoting $y_i \equiv w_i - l - t_i$, $a_i \equiv x - s_i$ and $z_i \equiv p - q_i - r_i$, yields the budget constraint:

$$y_i = C_i + z_i P_i + a_i X_i \tag{7}$$

For there to be a solution in which not every individual lives in the centre we require $z_i > 0$ so that there is a positive price on proximity. From equations (4) – (6) this in turn implies that the price of land rises more steeply than does the rate of increase in wages net of transport costs as proximity increases. This extra increase in the price of land compensates for the gain in

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[8] One can imagine a circle around a core city for which all points have equal P_i but where different points on that circle have unique amenity characteristics (i.e. a differing X_i).

utility that greater proximity causes. Similarly, we assume that $a_i > 0$ so that location-specific amenities are positively priced over and above any wage premium related to those amenities. The utility function (2) and the budget constraint (7) make it clear that there are individual-specific parameters in the individual's maximisation problem; thus different individuals will choose to locate in different places based on their individual preferences and constraints.

Maximisation of (2) subject to (7) gives the following solutions for C_i, P_i and X_i:

$$C_i = \left(\frac{\beta_i}{\beta_i+\delta_i Q+\alpha_i}\right) y_i \quad (8)$$

$$P_i = \left(\frac{\delta_i Q}{\beta_i+\delta_i Q+\alpha_i}\right) \frac{y_i}{z_i} \quad (9)$$

$$X_i = \left(\frac{\alpha_i}{\beta_i+\delta_i Q+\alpha_i}\right) \frac{y_i}{a_i} \quad (10)$$

The results in (8) - (10) are each partial equilibrium results relating to individual i; they are not general equilibrium results. For instance, if amenities in a particular location were to rise, not only would people wish to move to that location but land prices in that location would also rise. Similarly, if transport costs were to increase, land prices in the core location and/or the land price gradient would alter. Any general equilibrium model that solves for all parameters necessarily involves restrictive assumptions over available land supply and the distribution of preferences and constraints (i.e. over all the i-subscripted variables) across the entire population (including workers and non-workers). While some models make such assumptions in order to derive explicit solutions,[9] the assumptions are inevitably location-specific and may not hold in other cases. We instead explore partial equilibrium implications of our model and note where these implications may be tempered by general equilibrium adjustments.

The following partial equilibrium implications hold. First, if there is an increase in real income (net of land rents and transport costs) capable of being earned by the individual at the peripheral location (y_i),[10] the individual will increase her consumption (C_i) and choose her location so that she is both closer to the core city and can enjoy more location-specific amenities.

Second, if z_i increases, proximity to the core will decline. An increase in z_i (and hence a reduction in proximity) may reflect an increased land price gradient (making it cheaper to live more distant from the core), a decreased productivity premium associated with proximity to the

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[9] For instance, Desmet and Rossi-Hansberg (2013).

[10] And hence an increase in net income of all locations given the linear nature of the constraints.

core, and/or a reduction in transport costs that enables individuals to access core amenities at lower cost for any given degree of proximity.

Third, an exogenous increase in core city amenities (Q) will lead to individuals wishing to increase their proximity to the core city at the expense of other forms of consumption including amenities in other locations. The increase in proximity corresponds to an inflow of population to locations in or near the core city.

Fourth, if the cost of location-specific amenities decreases and/or the wage premium associated with location-specific amenities increases, the individual will substitute into those locations and so increase their consumption of location-specific amenities. The model does not explicitly model an exogenous increase in the provision of amenities in non-core areas, but this situation can be conceptualised as a reduction in price for such amenities (i.e. a reduction in x and hence in a_i). The reduction in a_i in turn causes increased consumption of these amenities, inducing a population inflow to the affected location.

In general equilibrium, land prices (conditioned by the parameters l, p and x) will adjust in response to other factors to effect a spatial equilibrium over time. For instance, an increase in amenities within the core (with an accompanying population influx) is likely to raise land prices in and around the core city and hence p will increase. The equilibrium outcome will reflect factors such as land supply elasticities in alternative locations. We assume, however, that planning and topographical constraints are not so rigid as to fully offset the directions of impact derived from the partial equilibrium results, especially in the short run; thus population flows are expected to be in accordance with the partial equilibrium predictions.

The model above is one of static equilibrium. To convert this model into one that has implications for the determinants of population growth (rather than just population levels), consider an extension in which the spatial parameters in the wage function (q_i and s_i) are themselves functions of the sizes of the core city and of other localities. If there is an increase in core city amenities (Q) this causes an initial population influx which, if there are positive agglomeration externalities, increases core city productivity, and hence drives q_i upwards. The increase in q_i in turn reduces z_i which further raises desired proximity to the core city so accentuating the influx and raising productivity still further. A one-time increase in core city amenities may therefore lead to a prolonged population inflow to the core city. This dynamic process may mean that an infrastructure investment can have a long-lived impact on the population growth rate of a city, and not just affect its population level. Conversely, if negative congestion effects predominate, the initial influx will be curtailed as productivity declines, partially offsetting the initial population influx. Similar dynamic effects potentially operate for the non-core localities.

Based on this theoretical outline, our empirical work utilises the change-level functional form summarised in Section 2 to test whether existing population size has a positive or negative effect on population growth rates, consistent with positive externality or negative congestion effects. We also test whether proximity to core cities[11] affects population growth rates, and we examine the impacts on population growth of natural and social amenities and infrastructure. We divide amenities into those that we expect to have productive benefits and those that have non-productive benefits, with some investments potentially contributing to both sets.

4. Population Growth Empirics

4.1. Modelling Approach

Given this theoretical framework, we examine the historical population growth rates of 56 New Zealand towns over 1926-2006. Our population data consist of eight waves of decennial census figures taken from the New Zealand Urban Population Database, described in detail in Grimes and Tarrant (2013)[12]. The unequal fortunes of New Zealand towns are made plain in Figure 1, which plots the average annual growth rates of the ten fastest- and ten slowest-growing towns over this 80-year period. The distribution of urban population growth rates over time is represented via box plots in Figure 2. Population growth rates were highest in the first two decades after World War II, and several North Island towns experienced dramatic growth in the decade to 1966. In the two decades between 1986 and 2006, however, slightly over half of the 56 towns experienced negative growth. (Summary statistics for average annual population growth by decade are presented in the Appendix, Table A2.)

[11] In our empirical work, proximity is inverted so that we model the effect of distance from the core cities.

[12] Towns are included in the database if they meet at least one of the following criteria: (a) they were categorised as an "urban area" by SNZ in 2006; (b) they were categorised as a "secondary urban area" by SNZ in 1986; (c) the borough population was at least 3,000 in 1956; or (d) the borough population was at least 1,500 in 1926. These criteria ensure that all significant towns in 1926 and 1956 are included, as well as larger urban areas in 1986 and 2006. As detailed in Grimes and Tarrant, the use of 2006 definitions of urban areas and secondary urban areas means that we treat towns that have effectively merged over time as a single urban area (even if they were separate in 1926). Three of the 60 towns in the database were not included in our study as data are not available for some years. Bluff (which may be considered an adjunct town to Invercargill) was found to be an influential negative outlier in some regressions so was also excluded from the analysis, reducing the final number of towns to 56. The data are available here: http://www.motu.org.nz/building-capacity/dataset/new_zealand_urban_population_data

Figure 1: Annualised Population Growth Rates, Top and Bottom 10 Towns (1926-2006)

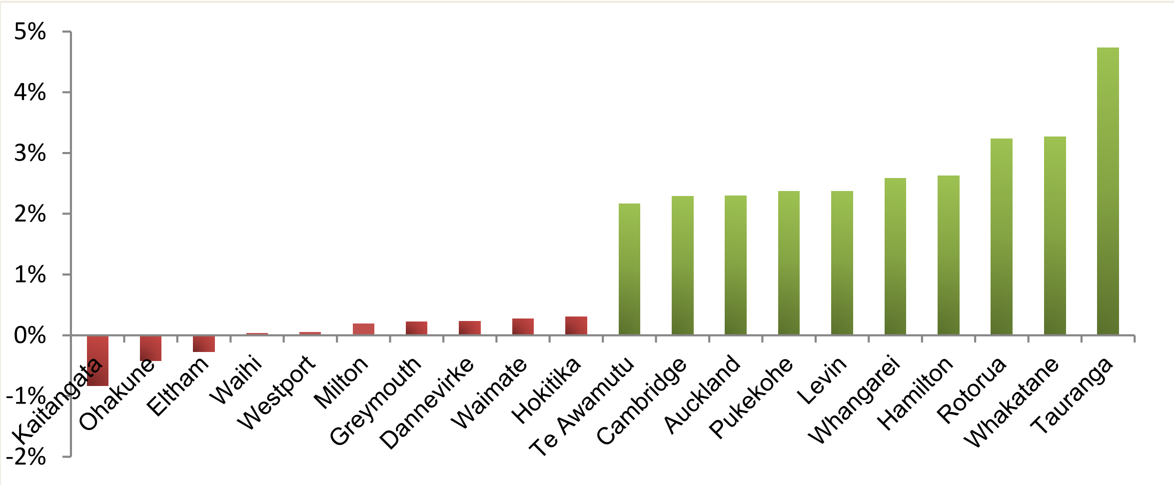
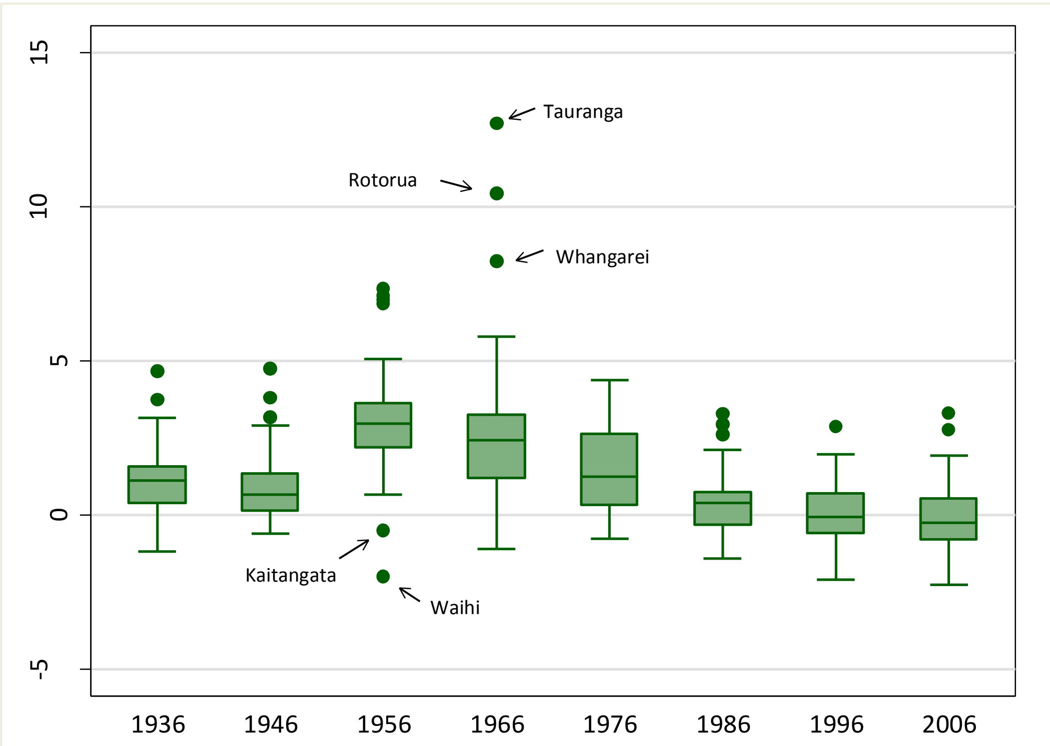


Figure 2: The Distribution of Average Population Growth by Decade



We estimate variations of the following general model:

$$\ln N_{jt} = \alpha \ln N_{jt-1} + \boldsymbol{\beta_1 R_j} + \boldsymbol{\beta_2 A_j} + \boldsymbol{\beta_3 D_j} + Time_t + \mu_j + e_{jt} \quad (11)$$

Or equivalently:

$$\Delta \ln N_{jt} = (\alpha - 1) \ln N_{jt-1} + \boldsymbol{\beta_1 R_j} + \boldsymbol{\beta_2 A_j} + \boldsymbol{\beta_3 D_j} + Time_t + \mu_{ji} + e_{jt} \quad (12)$$

where $\ln N_{jt}$ is the population of town j in period t in logs; $\boldsymbol{R_j}$ and $\boldsymbol{A_j}$ are vectors of local productivity and amenity characteristics respectively; and $\boldsymbol{D_j}$ is a vector of geographical variables to capture the effects of distance from core city amenities and productivity advantages. We include time fixed effects to control for national-level demographic trends[13], and we assume that the error component contains a town fixed effect (μ_j) and an idiosyncratic error e_{jt} that may be correlated within j. We estimate the model for the full time span (1926-2006) as well as for two subsamples (1926-1966 and 1966-2006) to allow for the possibility that the dynamics of population growth may have changed over time. In particular, the importance of local amenities and distance from the core city may have increased over time, as discussed in Section 3. Moreover, some modern infrastructure covariates (such as dummies for airports and polytechnics) are only relevant to the 1966-2006 period.

4.2. Explanatory Variables

Table 1 categorises the explanatory variables according to whether they relate to local productivity or local amenities (data sources are detailed in the Appendix, Table A1). Note that a number of variables (including the distance-related variables) are hypothesised to have a bearing on both sets of attributes. Where major infrastructure investments are concerned, we chose long-lived infrastructure that was built at or before the beginning of the time period in order to minimise the potential for endogeneity. Nonetheless, we treat these variables as potentially endogenous, since their construction may have anticipated known growth trends.

Variables intended to capture local productivity attributes include: road distance to port near the start of the time period; dummies for the presence of universities and polytechnics; a human capital proxy; and average land-use capability (LUC), a measure of the suitability of nearby land for agriculture[14]. We do not have longstanding measures of human capital to utilise; instead, we use 1946 Māori population as a percentage of total town population, noting that

[13] Data limitations mean that we cannot control for changing town-specific demographic factors such as age-structure.
[14] To derive this measure, we averaged the LUC index values across all 2006 Census meshblocks within each Territorial Local Authority (TLA), weighted by meshblock land area (and we transformed the variable so that higher values corresponded to better agricultural land). Each town was then assigned the average LUC of the TLA that it falls within. A detailed description of the LUC index can be found in Lynn et al. (2009).

throughout post-European settlement of New Zealand, Māori students have consistently had much lower pass rates in school examinations than do Europeans (Pākehā)[15, 16]. We expect local agricultural productivity (as proxied by LUC) to be a potentially important wage determinant given that many towns in our dataset may be characterised as agricultural service centres[17].

In keeping with the importance of climate in the international literature, average annual sunshine hours, average annual rainfall and average maximum summer and winter temperatures were initially included as natural amenities[18]. The presence of an airport could have both amenity and productive value, and region dummies are included to capture amenity and productive differences across regions[19,20]. We also include 1932 road distance from each of the country's four main centres (Auckland, Wellington, Christchurch and Dunedin); once again, initial rather than current road distance is chosen to minimise potential endogeneity.

Finally, we include the lag of log population to test for agglomeration externalities. If, over the course of our sample, positive agglomeration externalities outweighed negative effects, then larger towns will have grown at a faster rate than smaller towns (corresponding to $\alpha>1$ in

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[15] For instance, despite improvements in Māori pass-rates in recent decades, Māori pass-rates for NCEA Level 2 in 2012 were 54.2% relative to a non-Māori pass-rate of 74.3% (New Zealand Ministry of Education, 2014). Furthermore, we note the persistence of Māori population proportions over time; the correlation coefficient between the 1946 and 1881 Māori proportions is 0.59. A regression using 2006 census data for the proportion of the adult population with post-school qualifications shows a significant negative coefficient on the 1946 Māori population proportion (after controlling for regions, population size and presence of a university). Similarly, a significant negative coefficient is found where the dependent variable is at least a school qualification.

[16] Data were not available for all towns and we had to approximate using the proportion Māori of the nearest neighbour. The resulting variable is quite coarse, with only 13 unique values. As a robustness check, we also estimated our regressions with the percentage Māori population in 1881. There are 28 unique values for the 1881 measure, and it has the advantage of being more clearly exogenous. However, the 1946 and 1881 measures produced the same qualitative results, so we retained the 1946 measure in order to be consistent with our other covariates (which are all observed between 1926 and 1966). We note that while our Māori population proportion variable is likely capturing human capital effects, we cannot rule out that it is also capturing some other correlated effects that we cannot identify separately.

[17] LUC may also correlate with land costs, though the direction of the relationship is unclear: on the one hand, less productive land at the city fringes will result in lower land prices for consumers (all else being equal), since the land has a lower value in its best alternative use; but if LUC is so low that the land is unsuitable for agriculture (e.g. wetlands and steep terrain) it will also generally be unsuitable for urban construction, corresponding to a lower land supply and therefore higher prices.

[18] The Pearson correlation coefficients between these climate variables and LUC are all very small, so we do not interpret sunshine hours as affecting agricultural productivity nor LUC as reflecting climate amenities.

[19] We use the following seven regional classifications: *Auckland* (within 200km of Auckland); *Greater Auckland* (all other North Island towns north of Lake Taupo); *Wellington* (within 200km of Wellington); *Greater Wellington* (all other North Island towns south of Lake Taupo); *Christchurch* (within 200km of Christchurch); *Greater Christchurch* (all other towns in Canterbury, Marlborough, Tasman or West Coast regions); and *Dunedin* (Otago and Southland). The first four regions are in the country's North Island and the last three are in the South Island. See Appendix Table A3 for a list of towns by region.

[20] We gathered data on hospitals from the 1926 SNZ Yearbook as another amenity measure, but we concluded that the definition of "hospital" at the time was too broad.

Equation 11). With reference to our theoretical model, this would occur if productivity (R_j) and/or amenities (A_j) are a positive function of population.

Table 1: Explanatory variables

Explanatory Variable	*Hypothesised to Influence:*	
	Productivity	Amenities
Log population$_{(t-1)}$	Y	Y
Road distance to main centres 1932	Y	Y
Region dummies	Y	Y
Average land-use capability	Y	-
Average annual sunshine hours	-	Y
Percentage Maori 1946	Y	-
Distance to port 1932	Y	-
University (1926/1966)	Y	-
Polytechnic 1966	Y	-
Airport 1966	Y	Y

4.3. Estimation Method and Identification Issues

Initial estimates of the model are undertaken using pooled ordinary least squares (POLS) without town fixed effects (because of the presence of unchanging explanatory variables as regressors). In estimating this model, however, we are vulnerable to dynamic panel bias, since the town fixed effect is contained in the lagged dependent variable as well as in the error term[21]. Unfortunately, the two main estimation methods which accommodate dynamic panel data, difference GMM (Arellano and Bond, 1991) and system GMM (Blundell and Bond, 1998), both have serious limitations when applied to persistent series such as our town population data: the lagged levels used in difference GMM estimation are weak instruments for population change if the series is close to a random walk (see Blundell and Bond (1998)); and the differenced population series used in system GMM will be invalid instruments for the levels equation if the correlation between log population and the town fixed effects is not constant over time (this is sometimes called the "constant correlated effects" assumption – see Bun and Sarafidis (2013))[22].

Taking the (upward-biased) pooled OLS and (downward-biased) fixed effects estimates of 1.02 and 0.78 as bounds on the true value of α over 1966 to 2006, we concluded that the

[21] See Roodman (2009) for a detailed description of this issue.

[22] The "constant correlated effects" assumption of system GMM does not require mean stationarity, but it is a sufficient condition. See Bun and Sarafidis (2013) for a helpful discussion of this assumption.

difference GMM estimates of around 0.60 are indeed too low and so are not reported here[23]. The system GMM estimates are more plausible, ranging between 0.95 and 1.03 (see Section 4.5 for a discussion of the results across different specifications). Moreover, if the "constant correlated effects" assumption is violated (i.e. if the correlation between log population and the town fixed effects is increasing over time), then the system GMM estimates will be biased upwards. Given that the system GMM estimates of α generally lie below the upward-biased pooled OLS estimates, we can conclude that system GMM is a small improvement on pooled OLS whether or not the constant correlated effects assumption holds. Therefore, we adopt system GMM as our preferred estimation method for the 1966-2006 subsample, though we rely on POLS for the 1926-1966 and 1926-2006 regressions owing to the lack of early population data to use as instruments.

Collinearity is another serious identification concern. As shown in Table 2, our main infrastructure measures are highly correlated with population (and hence one another), leaving us unable to identify the separate effects of infrastructure variables on population growth. Of course, any variable that has an influence on percentage population growth will eventually be correlated with population level, and we suspect that the observed correlation between population and distance to port is due to a causal effect on early settlement patterns. Unfortunately, we lack the statistical power to separate out any continued effect of proximity to port from the agglomeration or congestion effects of population.

We face a similar problem with universities, polytechnics and airports. These are investments that were made in towns that were already relatively large, so once again we have little power in testing for their individual effects on population growth[24]. Moreover, any observed effect could be the result of reverse causation, and the bias could be positive or negative: for example, an airport may be more likely to be built in a town that is expected to grow in future, while a polytechnic might be built in an effort to revive a town that is expected to decline. Similarly, the estimated effects could suffer from omitted variables bias, since they may be correlated with unobserved infrastructure or other town attributes embodied in the fixed effect. We address these two potential sources of endogeneity by including additional historical instruments in the system GMM framework, namely log population in 1901 (and a dummy for

[23] This is consistent with a weak instrument problem biasing the results towards the OLS estimate of α in first differences, which comes out at 0.42. Difference GMM has the added disadvantage that the coefficients and standard errors for the time-invariant regressors have to be backed out in a two-step procedure rather than estimated directly.
[24] Note also that there are only six New Zealand cities with a university home campus (four of which had a university before 1926), so we have little variation to work with when trying to single out the effect of universities on growth even in the absence of collinearity issues.

no 1901 population data) and the 1880 Railway Commission's recommendation for local railway development ("has rail", "to be prioritised", "to be postponed", and "not recommended").

Table 2: Pearson Correlations with Population

Explanatory Variable	***Correlation with lag of log population***		
	1926-2006	**1926-1966**	**1966-2006**
1932 distance to port	-0.468	-0.517	-0.455
1926 university	0.640	0.701	-
1966 university	-	-	0.685
1966 polytechnic	-	-	0.520
1966 airport	-	-	0.747

4.4. Pooled OLS Results

Results from pooled OLS regressions of population growth over each of the three timespans (i.e. 1926-2006, 1926-2006 and 1966-2006) are shown in Table 3. The dependent variable is the decade change in log population. In light of the high degree of collinearity between log population and the infrastructure variables (distance to port and dummies for universities, polytechnics and airports), we estimated three different specifications for each time period: the lag of log population with the full suite of time-invariant variables; the time-invariant variables only; and the lag of population plus a minimal set of time-invariant regressors that excludes the collinear infrastructure variables.

Unsurprisingly, we find signs of collinearity in our results. The population lag enters with a positive and significant coefficient in all three time periods, but the effect is always smaller (and in one case insignificant) when the collinear infrastructure variables are excluded. Moreover, the coefficients on these infrastructure variables are unstable across specifications: although there are relatively large and significant effects in several instances, these entirely drop away with the addition or removal of the log population lag. We defer further discussion of the population lag and infrastructure variables to the system GMM subsection below.

The estimates for our distance-related variables are more informative. Over 1966-2006, there are large negative effects associated with most of New Zealand's regions compared with the "Auckland" region, which includes the country's largest city and towns within a 200km radius. The two regions that fare best in comparison to Auckland, entering with small, insignificant (but nonetheless negative) coefficients, are "Greater Auckland", which includes towns between 200 and 320 kilometres from Auckland, and "Christchurch", which encompasses the South Island's largest city and its near neighbours. By contrast, the only sizeable and significant region effect in the 1926-1966 subsample is that for Greater Auckland, which we expect reflects the exceptional growth of Tauranga and Rotorua over 1956-1966 (see Figure 2 above). Taken together, these results suggest that proximity to the major population centre of each island, and especially Auckland, has been a driver of urban growth in recent decades, but was not important in the first half of the 20th century.

We also included distance to each of the four main centres as a finer measure of proximity. We expect any effect over and above what is picked up by the region dummies to be fairly localised, so we set distance to zero for towns that aren't in the same region as the relevant main centre[25]. While the coefficients are generally negative, particularly in the 1966-2006 regressions, we find no significant distance effect. However, we note that we have very little power to detect any such effect, since there are only a small number of towns in each region (see Appendix Table A3).

Turning to our (non-infrastructure) productivity and amenity variables, we see that land-use capability – our proxy for agricultural productivity – has a positive and significant effect that is consistent across all three time periods and all different specifications. Climate, as measured by annual sunshine hours, is another factor with a positive impact on population growth over the whole time period, in line with findings from other countries (see, for example, Rappaport, 2007, 2008 and 2009; Rappaport and Sachs, 2003)[26]. Meanwhile our education proxy, the Māori ethnicity proportion of the population in 1946, has a negative and significant coefficient in the 1966-2006 regressions but not in the earlier subsample. This result is consistent with Apatov (2013), who highlights the importance of local human capital for regional population growth in recent years.

Finally, note that we have modelled the interrelations between each town and its nearest neighbours explicitly, by including regional controls and linear distance effects. It is possible that our model fails to adequately capture more complex spatial interactions that may be at work, in which case a spatial econometric model would be more appropriate. To explore this possibility, we calculated Moran's I for each decade, with weights equal to the inverse of the distance

[25] In earlier regressions (not reported here), we experimented with linear and quadratic distance to each main centre for all towns in the same island (rather than just the same region), and we also tested travel time and the ratio of time to distance. In all cases, there was no significant negative distance effect.

[26] Our other climate measures – rainfall and average summer and winter temperatures – were never significant in any combination when included with and without sunshine hours. We omit these variables out of concern for degrees of freedom, noting that their exclusion does not affect the other coefficient estimates.

between each town[27]. Across all of our specifications, the Moran's I statistic is small and almost always insignificant, indicating that no additional spatial modelling is necessary.

4.5. System GMM Results

Our system GMM estimates are displayed in Table 4. Given that a number of lags of the dependent variable are needed as instruments, we only estimate the regressions for the 1966-2006 subsample. Note that (log) population is our dependent variable rather than the first difference, so we subtract one from the coefficient on the population lag in order to compare the estimates with those from pooled OLS (see Equations 11 and 12). We obtained one-step and two-step GMM estimates for models with and without the collinear infrastructure variables, and also tested the sensitivity of the results to the size of the instrument set. Estimates excluding the infrastructure variables are shown in Columns 1 through 8, with more restrictions on the instruments imposed each time: the first specification (Columns 1 and 2) utilises all available lags of population as GMM-style instruments (i.e. going back to 1926), while the estimates in Columns 7 and 8 are obtained with only the first lag[28]. Finally, in the last two columns we report estimates from the model including the infrastructure variables, making use of the additional historical instruments discussed in Section 4.3.

Most of the significant trends observed in the OLS results for 1966-2006 reappear in the system GMM estimates: the regions nearest to the country's two largest cities have fared best (and within those regions, distance from the core city has a negative, albeit insignificant, influence on growth); land-use capability and sunshine hours are positively associated with population growth; and towns with lower education levels have enjoyed less growth. However, the positive and significant relationship between the lag of population and population growth is no longer present: we now find the effect is insignificant in all but one of the 10 regressions, with some estimates even slightly negative. Given that OLS produces positively biased estimates when applied to dynamic panel data, and that any bias in the system GMM estimates would also be positive, we lend most weight to the system GMM estimates and conclude that there is no discernible generalised agglomeration or congestion effect other than that associated with being in the Auckland region.

Collinearity amongst the infrastructure variables and the population lag once again clouds our view of the individual infrastructure effects, though the pattern is reversed in the system GMM estimates: inclusion of the infrastructure variables now lowers rather than raises the

[27] We set the weights to zero for towns not in the same island, i.e. we assumed that North Island towns exert no influence on South Island towns, and vice versa.

[28] By this we mean the first lag of log population$_{(t-1)}$, i.e. log population$_{(t-2)}$.

coefficient on the log population lag. The estimated negative effect associated with distance to port is much larger than in the OLS results, even after instrumenting, and likewise with the positive effect relating to the presence of an airport. However, we note that these estimates, while suggestive, are statistically insignificant.

4.6. A Test for Omitted Variables

Several of our regressors are imperfect proxies for our true variables of interest (1946 percentage Māori, land-use capability, sunshine hours), and it's possible that the significant effects associated with them reflect other, omitted factors. The coefficients on our infrastructure variables may also be affected by omitted variable bias, particularly if important unobserved infrastructure investments were made in the same towns as the observed infrastructure. Moreover, some of our significant effects are open to multiple interpretations *a priori*: for example, does proximity to Auckland (as measured by the region dummies) bring amenity value or productive value?

In order to check for the possibility of omitted variables in our regressions, and to gain a better understanding of the different factors at work, we turned to the Territorial Local Authority (TLA) rankings created by Donovan (2011). Donovan used Census income and rent data from 1996, 2001 and 2006 to rank TLAs according to their (revealed preference) attractiveness for "business" and "life"[29]. We took the average rankings across the three years as measures of the value accorded to earnings opportunities and amenities respectively towards the end of our sample. We added a quadratic in each ranking to our OLS regressions to test whether amenity or productive factors that are reflected in rents and wages added significantly to our included explanatory variables in explaining population growth. The coefficients on the quadratics were insignificant and the other estimates virtually unchanged, providing some assurance that our estimates do not suffer from omitted variables bias.

Separately, we regressed each of the business and amenity ranking variables against the 2006 values of our covariates to analyse which variables influence revealed preference amenity and productivity values across towns at the end of our sample. The results are shown in Table 5 (noting that negative coefficients correspond to higher rankings). Relative to the Auckland

[29] Donovan calculated the *life* index as $(r - w)$, where r is the average rent paid by households in the TLA adjusted for housing quality (number of rooms, etc.), and w is the average household income in the TLA, adjusted for observable characteristics such as education level and household size. This index reflects a spatial equilibrium approach in which people pay high rents relative to wages so as to access positive local amenities. The *business* index is defined as $(r + w)$, with household rent proxying for commercial rent. This index also reflects a spatial equilibrium approach in which firms that choose a highly productive locality can pay higher wages and must pay higher rents to reflect the more productive location.

region, all other regions fare better in the amenity rankings and worse in the business rankings, suggesting that proximity to Auckland has brought earnings rather than quality of life advantages. Maré and Graham (2013), using unit record data, also find that Auckland is more productive (even after controlling fior industry mix) than other regions of New Zealand. Nonetheless, we see that larger towns are in general associated with higher rankings for both business and amenities. There is no effect associated with 1946 percentage Māori in the business rankings, suggesting some caution is needed in interpreting its significance as a productivity measure in our main regressions. However, we are reassured that land-use capability and distance to port are reflected significantly in business rankings with the expected sign, and sunshine hours has the expected sign for the amenity rankings.

Table 3: Pooled OLS Estimates

Dependent variable: $\Delta(Log\ population_t)$	1926-2006 (1)	(2)	(3)	1926-1966 (4)	(5)	(6)	1966-2006 (7)	(8)	(9)
Log population$_{(t-1)}$ $(\hat{\alpha}-1)$	0.021**		0.013**	0.029**		0.012	0.023**		0.019***
	(0.009)		(0.006)	(0.013)		(0.009)	(0.011)		(0.006)
Road distance to Auckland 1932	-0.038	-0.031	-0.019	-0.020	-0.009	0.015	-0.060	-0.066	-0.043
	(0.058)	(0.069)	(0.061)	(0.076)	(0.086)	(0.078)	(0.053)	(0.057)	(0.055)
Road distance to Wellington 1932	-0.010	0.010	0.040	-0.056	-0.029	0.007	0.042	0.042	0.085**
	(0.054)	(0.062)	(0.045)	(0.067)	(0.073)	(0.064)	(0.052)	(0.058)	(0.040)
Road distance to Christchurch 1932	-0.061	-0.040	-0.014	-0.052	-0.022	0.001	-0.073	-0.085	-0.021
	(0.045)	(0.037)	(0.043)	(0.049)	(0.054)	(0.034)	(0.088)	(0.085)	(0.083)
Road distance to Dunedin 1932	-0.023	0.020	0.022	-0.001	0.056	0.061**	-0.068*	-0.048	-0.018
	(0.030)	(0.030)	(0.015)	(0.043)	(0.042)	(0.028)	(0.040)	(0.039)	(0.019)
Region (Auckland omitted)									
Wellington	-0.053	-0.057	-0.071	0.028	0.025	0.013	-0.142***	-0.151***	-0.158***
	(0.050)	(0.056)	(0.059)	(0.075)	(0.077)	(0.084)	(0.046)	(0.050)	(0.057)
Christchurch	-0.035	-0.043	-0.045	-0.021	-0.03	-0.031	-0.048	-0.055	-0.058
	(0.041)	(0.046)	(0.055)	(0.058)	(0.062)	(0.063)	(0.063)	(0.064)	(0.080)
Greater Auckland	0.062	0.080	0.086	0.177**	0.191**	0.216***	-0.060	-0.062	-0.037
	(0.059)	(0.063)	(0.059)	(0.073)	(0.076)	(0.074)	(0.066)	(0.068)	(0.063)
Greater Wellington	-0.120**	-0.111*	-0.091*	-0.108*	-0.090	-0.067	-0.132**	-0.146**	-0.105*
	(0.053)	(0.060)	(0.054)	(0.061)	(0.067)	(0.061)	(0.062)	(0.066)	(0.061)
Greater Christchurch	-0.091	-0.074	-0.059	-0.056	-0.029	-0.012	-0.128**	-0.154**	-0.100
	(0.056)	(0.063)	(0.054)	(0.072)	(0.077)	(0.070)	(0.063)	(0.067)	(0.060)
Greater Dunedin	-0.059	-0.082	-0.066	-0.017	-0.046	-0.034	-0.083	-0.125**	-0.092
	(0.052)	(0.059)	(0.059)	(0.076)	(0.077)	(0.077)	(0.054)	(0.055)	(0.064)
Average land-use capability	0.023**	0.029***	0.026***	0.029*	0.035**	0.033**	0.018**	0.020**	0.018**
	(0.010)	(0.010)	(0.010)	(0.016)	(0.015)	(0.015)	(0.008)	(0.008)	(0.007)
Average annual sunshine hours	0.024***	0.026***	0.026***	0.026***	0.027***	0.026***	0.020***	0.020***	0.024***
	(0.004)	(0.004)	(0.004)	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)	(0.004)
Percentage Maori 1946	-0.005	-0.004	-0.005	0.005	0.007	0.005	-0.015**	-0.016**	-0.017**
	(0.007)	(0.008)	(0.007)	(0.014)	(0.012)	(0.013)	(0.006)	(0.006)	(0.007)
Road distance to port 1932	-0.012	-0.034		0.021	-0.008		-0.022	-0.050**	
	(0.032)	(0.030)		(0.047)	(0.045)		(0.028)	(0.025)	
University 1926	-0.089*	-0.005		-0.127*	-0.010				
	(0.048)	(0.039)		(0.066)	(0.051)				
University 1966							-0.025	0.004	
							(0.046)	(0.041)	
Polytechnic 1966							-0.053	-0.035	
							(0.040)	(0.036)	
Airport 1966							0.009	0.043*	
							(0.023)	(0.022)	
N	448	448	448	224	224	224	224	224	224
R-squared	0.606	0.596	0.602	0.537	0.524	0.529	0.631	0.620	0.621
Moran's I									
1936	0.013	0.014	0.007	0.044	0.043	0.040			
1946	-0.003	0.001	-0.004	0.039	0.042	0.038			
1956	-0.076	-0.081	-0.081	-0.097*	-0.104*	-0.101*			
1966	-0.035	0.028	0.029	-0.006	-0.006	-0.008			
1976	-0.046	-0.044	-0.056				-0.095	-0.090	-0.096
1986	0.010	0.020	0.007				0.046	0.043	0.042
1996	0.035	0.016	0.025				-0.023	-0.035	-0.027
2006	0.124***	0.088**	0.101**				0.032	0.015	0.019

Notes: All regressions include an intercept and time fixed effects. Standard errors clustered on town in parentheses. Road distances are in 100s of miles. * p<.1, ** p<.05, *** p<.01

Table 4: System GMM Estimates, 1966-2006

Dependent variable: $\boldsymbol{Log\ population_t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log population$_{(t-1)}$ ($\hat{\alpha}$)	0.994***	0.989***	0.997***	0.992***	1.011***	1.020***	1.025***	1.031***	0.949***	0.959***
($\hat{\alpha} - 1$)	*-0.006*	*-0.011*	*-0.003*	*-0.008*	*0.011*	*0.020*	*0.025***	*0.031*	*-0.051*	*-0.041*
	(0.017)	(0.022)	(0.017)	(0.022)	(0.013)	(0.024)	(0.012)	(0.022)	(0.041)	(0.067)
Road distance to Auckland 1932	-0.091	-0.089	-0.086	-0.080	-0.058	-0.074	-0.031	-0.068	-0.119**	-0.100
	(0.061)	(0.086)	(0.060)	(0.091)	(0.046)	(0.078)	(0.039)	(0.076)	(0.053)	(0.075)
Road distance to Wellington 1932	0.030	0.044	0.035	0.051	0.068	0.099	0.098**	0.119**	0.020	0.058
	(0.068)	(0.100)	(0.065)	(0.096)	(0.049)	(0.070)	(0.039)	(0.059)	(0.080)	(0.111)
Road distance to Christchurch 1932	-0.053	-0.067	-0.050	-0.058	-0.031	-0.063	-0.014	-0.058	-0.197	-0.192
	(0.045)	(0.057)	(0.048)	(0.068)	(0.067)	(0.072)	(0.089)	(0.113)	(0.122)	(0.192)
Road distance to Dunedin 1932	-0.015	-0.011	-0.015	-0.010	-0.017	-0.022	-0.019	-0.030	-0.081	-0.080
	(0.049)	(0.062)	(0.045)	(0.064)	(0.024)	(0.033)	(0.019)	(0.025)	(0.071)	(0.117)
Region (omitted category: Auckland)										
Wellington	-0.145**	-0.134	-0.147**	-0.130	-0.154***	-0.189**	-0.161***	-0.222**	-0.186***	-0.208**
	(0.069)	(0.103)	(0.067)	(0.112)	(0.058)	(0.094)	(0.060)	(0.109)	(0.063)	(0.095)
Christchurch	-0.061	-0.025	-0.061	-0.019	-0.059	-0.029	-0.057	-0.038	-0.063	-0.026
	(0.061)	(0.087)	(0.061)	(0.102)	(0.068)	(0.096)	(0.083)	(0.129)	(0.066)	(0.113)
Greater Auckland	-0.069	-0.048	-0.066	-0.040	-0.047	-0.067	-0.029	-0.086	-0.137*	-0.119
	(0.057)	(0.085)	(0.056)	(0.097)	(0.050)	(0.090)	(0.052)	(0.104)	(0.072)	(0.112)
Greater Wellington	-0.152***	-0.123	-0.147**	-0.117	-0.119**	-0.129	-0.093**	-0.139	-0.222***	-0.198**
	(0.058)	(0.083)	(0.058)	(0.094)	(0.047)	(0.081)	(0.046)	(0.088)	(0.072)	(0.093)
Greater Christchurch	-0.134**	-0.117	-0.130**	-0.101	-0.110**	-0.118	-0.091*	-0.135	-0.271**	-0.228*
	(0.059)	(0.088)	(0.058)	(0.097)	(0.049)	(0.082)	(0.049)	(0.092)	(0.108)	(0.128)
Greater Dunedin	-0.117*	-0.092	-0.115*	-0.087	-0.100*	-0.110	-0.086	-0.120	-0.252***	-0.228
	(0.069)	(0.093)	(0.067)	(0.109)	(0.055)	(0.088)	(0.057)	(0.099)	(0.091)	(0.156)
Average land-use capability	0.024**	0.026**	0.023**	0.027**	0.020**	0.017	0.016**	0.012	0.032	0.036
	(0.010)	(0.012)	(0.009)	(0.013)	(0.008)	(0.012)	(0.007)	(0.011)	(0.021)	(0.034)
Average annual sunshine hours	0.030***	0.034***	0.030***	0.032***	0.026***	0.023***	0.023***	0.021**	0.008	0.012
	(0.007)	(0.008)	(0.006)	(0.008)	(0.006)	(0.009)	(0.005)	(0.008)	(0.012)	(0.023)
Percentage Maori 1946	-0.013	-0.014	-0.014	-0.013	-0.015**	-0.016	-0.017***	-0.017**	-0.015	-0.016
	(0.011)	(0.016)	(0.010)	(0.014)	(0.008)	(0.010)	(0.006)	(0.008)	(0.012)	(0.016)
Road distance to port 1932									-0.102	-0.098
									(0.069)	(0.094)
University 1966									-0.057	-0.066
									(0.198)	(0.281)
Polytechnic 1966									0.032	0.036
									(0.170)	(0.224)
Domestic Airport 1966									0.201*	0.168
									(0.117)	(0.226)
N	224	224	224	224	224	224	224	224	224	224
GMM estimator										
One-step	X		X		X		X		X	
Two-step		X		X		X		X		X
Instruments										
Total number of instruments	43		37		29		25		32	
Longest lag of Log population$_{(t-1)}$	7		4		2		1		1	
External instruments for universities, polytechnics, airports									Y	
Moran's I										
1976	-0.061	-0.062	-0.064	-0.067	-0.084	-0.097	-0.105*	-0.109*	-0.097	-0.099
1986	0.082**	0.083**	0.079**	0.097**	0.058	0.089**	0.028	0.073*	0.004	0.034
1996	-0.028	-0.018	-0.027	-0.021	-0.025	-0.034	-0.030	-0.037	-0.086	-0.071
2006	0.006	0.011	0.008	0.005	0.018	-0.020	0.018	-0.038	-0.043	-0.050

Notes: All regressions include an intercept and time fixed effects. Standard errors clustered on town in parentheses. Two-step GMM standard errors use the Windmeijer correction (see Roodman (2009)). Road distances are in 100s of miles. * p<.1, ** p<.05, *** p<.01

Table 5: OLS regressions of average TLA rankings, 1996-2006

Dependent variable: *Average TLA ranking*	Amenity ranking (1)	Amenity ranking (2)	Business ranking (3)	Business ranking (4)
Log population 1986	-3.054	-4.416***	-1.055	-4.432***
	(3.341)	(1.564)	(2.448)	(1.181)
Initial road distance to Auckland	-6.934	-7.632	10.592	14.193*
	(11.559)	(10.475)	(8.467)	(7.909)
Initial road distance to Wellington	-9.148	-4.723	16.657	15.139
	(16.913)	(15.383)	(12.388)	(11.615)
Initial road distance to Christchurch	3.000	13.250	18.740	12.640
	(17.506)	(14.937)	(12.823)	(11.278)
Initial road distance to Dunedin	25.128	33.352***	-12.416	-11.323
	(14.966)	(12.203)	(10.962)	(9.213)
Region (omitted category: Auckland)				
Wellington	-12.368	-17.006	17.688	19.423
	(16.867)	(16.461)	(12.355)	(12.429)
Christchurch	-23.656	-26.616*	22.146*	22.217*
	(15.535)	(15.409)	(11.379)	(11.635)
Greater Auckland	-3.982	-4.207	13.844	18.781**
	(13.913)	(12.035)	(10.191)	(9.087)
Greater Wellington	-7.850	-5.024	25.092***	23.507***
	(12.504)	(11.325)	(9.159)	(8.551)
Greater Christchurch	-35.819**	-34.928**	34.223***	30.424***
	(15.771)	(14.084)	(11.552)	(10.634)
Greater Dunedin	-51.994***	-51.241***	56.765***	50.177***
	(16.654)	(15.174)	(12.199)	(11.457)
Average land-use capability	1.998	0.873	-4.128**	-3.873**
	(2.484)	(2.322)	(1.820)	(1.753)
Average annual sunshine hours	-2.499	-1.085	-0.315	2.995
	(1.604)	(1.292)	(1.175)	(0.975)
Percentage Maori 1946	-1.563	-2.092	3.033	-1.121
	(3.283)	(3.268)	(2.405)	(2.468)
Road distance to port 1932	-10.404		17.319**	
	(9.344)		(6.845)	
University 1966	-17.156		-6.028	
	(12.627)		(9.249)	
Polytechnic 1966	2.698		2.119	
	(12.111)		(8.871)	
Airport 1966	-0.068		-3.997	
	(7.714)		(5.650)	
N	56	56	56	56
R-squared	0.571	0.524	0.771	0.731

Notes: Standard errors in parentheses. Road distances are in 100s of miles. * p<.1, ** p<.05, *** p<.01

5. Conclusions

We have analysed the key growth determinants of 56 New Zealand towns and cities over eight decades to 2006. Using a revealed preference framework, we argue that urban areas grow if they have a desirable combination of amenities and real earning opportunities relative to alternative locations. This framework is formalised within a theoretical model that includes distance-related and amenity effects on individual utility, incomes and costs. A number of factors may contribute to earnings opportunities and/or amenities including transport links, social infrastructure, benefits of location in a large population area, and natural amenities.

In testing our model, we face a number of econometric issues. First, there is a strong positive correlation of urban population with many of our infrastructure variables. This makes it difficult to identify urban growth impacts, for instance of higher educational institutions, that are separate from their location within a larger urban area. Second, we are cognisant that a number of transport and social amenity variables that we hypothesise are important determinants of urban growth may be endogenously determined. Consequently, we compile a range of long pre-determined variables to use as instruments. Third, we recognise that spatial lag or spatial error processes may affect urban growth patterns. We test whether such processes are important in explaining urban growth over the period, finding little empirical support for their presence once other spatial variables are controlled for explicitly.

Given the dynamic panel nature of our data, we adopt System GMM as our preferred estimation method. We find that four dominant factors have impacted positively on urban growth, especially since 1966: local land use capability, sunshine hours, human capital and proximity to major population centres, especially Auckland.

The last two elements are both potential sources of policy intervention. First, human capital can be raised through a generalised increase in the national standard of human capital and, at the local level, can be raised by developing and attracting high human capital to the area. The presence of universities (and possibly other HEIs) is correlated with an urban area having high relative human capital (Apatov, 2013), although the causality in this relationship is difficult to establish. Second, proximity to Auckland can be improved through the upgrading of transport links that make it easier for firms and people to locate near to, but outside of, Auckland while still accessing some of the amenity and productivity benefits offered by the city. Moreover, the importance of proximity to major agglomerations can be interpreted in an international context. Auckland, New Zealand's largest and most productive city, is small by international comparisons and is only the fifth largest urban area in Australasia. To the extent that urban growth across

Australasia is determined by similar factors to urban growth within New Zealand, there is a case that policy should at least facilitate, and certainly not overly constrain, the size of New Zealand's most productive city; otherwise the risk is that growth will increasingly be located in Australia's four largest cities rather than in Auckland and its surrounding region.

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Appendix

Table A1: Data Sources and Sample Means

Variable	Mean	Source
Log population	9.11	Motu (2013)
Average land-use capability[1]	2.89	Landcare Research and MAF (2002)
Average annual sunshine hours	1996	NIWA (2014)[2]
1932 road distance to Auckland (miles, Auckland region only)	87.08	Alexander Turnbull Library (2006)
1932 road distance to Wellington (miles, Wellington region only)	72.50	Alexander Turnbull Library (2006)
1932 road distance to Christchurch (miles, Christchurch region only)	56.40	Alexander Turnbull Library (2006)
1932 road distance to Dunedin (miles, Dunedin region only)	65.43	Alexander Turnbull Library (2006)
Region		
Auckland	0.21	
Wellington	0.14	
Christchurch	0.09	
Greater Auckland	0.09	
Greater Wellington	0.23	
Greater Christchurch	0.11	
Dunedin	0.13	
Percentage Maori 1881	13.69	National Library of New Zealand (2014a)
Percentage Maori 1946	1.38	Motu (2013)
Distance to port in 1932 (miles)	38.57	Alexander Turnbull Library (2006)
University 1926 (dummy)	0.07	Te Ara Encyclopedia of New Zealand (2014)
University 1966 (dummy)	0.10	Te Ara Encyclopedia of New Zealand (2014)
Polytechnic 1966 (dummy)	0.23	Dougherty (1999)
Airport in 1966 (dummy)	0.41	SNZ (various)
Average TLA "life" ranking, 1996-2006		Donovan (2011)
TLA "business" ranking, 1996-2006		Donovan (2011)
Instruments		
1880 has rail (dummy)	0.63	National Library of New Zealand (2014b)
1880 rail to be delayed (dummy)	0.13	National Library of New Zealand (2014b)
1880 rail to be prioritised (dummy)	0.07	National Library of New Zealand (2014b)
1901 population	8570	Motu (2013)
1901 population data missing (dummy)	0.30	Motu (2013)
Other data[3]		
1901 on coach route (dummy)		National Library of New Zealand (2014c)
1901 railroad (dummy)		National Library of New Zealand (2014c)
1901 steamer port (dummy)		National Library of New Zealand (2014c)
1906 port (dummy)		SNZ (various)
1906 port tonnage		SNZ (various)
1909 rail distance to Auckland (miles, Auckland region only)		New Zealand Railways (1937, 1957)
1909 rail distance to Christchurch (miles, Christchurch region only)		New Zealand Railways (1937, 1957)

Table A1 (cont'd): Data Sources and Sample Means

Variable	Mean	Source
1909 rail distance to Dunedin (miles, Dunedin region only)		New Zealand Railways (1937, 1957)
1909 rail distance to Wellington (miles, Wellington region only)		New Zealand Railways (1937, 1957)
1920 has a dairy factory (dummy)		Alexander Turnbull Library (2006)
1920 has a meatworks (dummy)		Alexander Turnbull Library (2006)
1926 university (dummy)		SNZ (various)
1968 road distance to Auckland (miles, Auckland region only)		Shadbolt (1968: p33)
1968 road distance to Wellington (miles, Wellington region only)		Shadbolt (1968: p33)
1968 road distance to Christchurch (miles, Christchurch region only)		Shadbolt (1968: p33)
1968 road distance to Dunedin (miles, Dunedin region only)		Shadbolt (1968: p33)
40-year population lag (in logs)		Motu (2013)
Average annual rainfall (mm)		NIWA (2014)
Average summer max temperature (degrees Celsius)		NIWA (2014)
Average winter max temperature (degrees Celsius)		NIWA (2014)
Straight-line distance to Auckland (km, Auckland region only)		GPS Visualizer (2014)
Straight-line distance to Christchurch (km, Christchurch region only)		GPS Visualizer (2014)
Straight-line distance to Dunedin (km, Dunedin region only)		GPS Visualizer (2014)
Straight-line distance to Wellington (km, Wellington region only)		GPS Visualizer (2014)
Hospital in 1916 (dummy)		SNZ (various)
Hospital in 1926 (dummy)		SNZ (various)
Hospital admissions 1915		SNZ (various)
Hospital admissions 1924		SNZ (various)
1968 road travel time to Auckland		Shadbolt (1968: p326)
1968 road travel time to Wellington		Shadbolt (1968: p326)
1968 road travel time to Christchurch		Shadbolt (1968: p326)
1968 road travel time to Dunedin		Shadbolt (1968: p326)
Total port tonnage (1916-1976)		SNZ (various)
Total number of vessels to port (1926-1976)		SNZ (various)
Aerodrome in 1936 (dummy)		SNZ (various)
Regular commercial flights (dummy, 1946-1956)		SNZ (various)
Port in 1903 (dummy)		SNZ (various)
Port (dummy, 1916-1976)		SNZ (various)
International flights (dummy, 1946-2006)		SNZ (various)
Permanent & long-term arrivals to NZ in decade *t*		SNZ (various)
Not connected to a main centre by rail in 1909 (dummy)		New Zealand Railways (1937, 1957)

Notes: All variables (including those listed under Other Data) are contained in the Motu Urban Population Database, available for download at http://www.motu.org.nz/building-capacity/dataset/new_zealand_urban_population_data.

[1] To derive this measure, we averaged the LUC index values across all 2006 Census meshblocks within each Territorial Local Authority (TLA), weighted by meshblock land area (and we transformed the variable so that higher values corresponded to better agricultural land). Each town was then assigned the average LUC of the TLA that it falls within. A detailed description of the LUC index can be found in Lynn et al. (2009).

[2] NIWA (2014) data were not available for 18 towns. In these cases, climate data were approximated with the values of the nearest neighbouring town.

[3] These variables are not used in the reported regressions.

Table A2: Summary Statistics

Unweighted Average Annual Population Growth by Decade (%)				
Year	**Mean**	**SD**	**Min**	**Max**
1936	1.08	1.10	-1.17	4.67
1946	0.95	1.12	-0.59	4.76
1956	3.04	1.69	-1.98	7.34
1966	2.69	2.45	-1.08	12.69
1976	1.45	1.35	-0.75	4.39
1986	0.36	0.94	-1.41	3.29
1996	0.08	0.94	-2.10	2.88
2006	-0.10	1.06	-2.25	3.31
All years	1.19	1.77	-2.25	12.69

Table A3: Region Classifications and Road Distances

Region Classifications and Road Distance to Each Main Centre

AUCKLAND	**Distance to Auckland (km)**
Auckland	*0*
Pukekohe	48
Huntly	100
Hamilton	134
Paeroa	137
Morrinsville	145
Cambridge	156
Waihi	159
Te Aroha	161
Te Awamutu	164
Whangarei	174
Dargaville	183

GREATER AUCKLAND	**Distance to Auckland (km)**
Te Kuiti	214
Tauranga	220
Rotorua	245
Taumaranui	299
Whakatane	320

WELLINGTON	**Distance to Wellington (km)**
Wellington	*0*
Carterton	90
Levin	100
Masterton	103
Foxton	119
Palmerston North	150
Feilding	172
Marton	172

GREATER WELLINGTON	**Distance to Wellington (km)**
Wanganui	203
Dannevirke	212
Waipukurau	269
Hawera	298
Ohakune	299
Hastings	317
Eltham	319
Stratford	330
Napier	341
New Plymouth	370
Waitara	370
Wairoa	468
Gisborne	575

CHRISTCHURCH	**Distance to Christchurch (km)**
Christchurch	*0*
Rangiora	32
Ashburton	87
Temuka	145
Timaru	159

GREATER CHRISTCHURCH	**Distance to Christchurch (km)**
Waimate	209
Greymouth	254
Hokitika	259
Blenheim	323
Westport	346
Nelson	441

DUNEDIN	**Distance to Dunedin (km)**
Dunedin	*0*
Milton	55
Balclutha	80
Kaitangata	90
Oamaru	117
Gore	159
Invercargill	224

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