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Climate Change, Internal Migration and the Future Spatial Distribution of Population: A Case Study of New Zealand

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Abstract

This paper evaluates the impact of climate change on the future spatial distribution of population in New Zealand, with a focus on the effects of climate variables on internal migration dynamics. Specifically, a gravity modelling framework is first used to identify climate variables that have statistically significant associations with internal migration. The gravity model is then embedded within a cohort-component population projection model to evaluate the effect of different climate change scenarios on regional populations. Three climate variables are found to have statistically significant associations with internal migration: (1) mean sea level pressure in the destination; (2) surface radiation in the origin; and (3) wind speed at ten metres at the destination. Including these variables in the population projection model makes a small difference to the regional population distribution, and the difference between different climate scenarios is negligible. Overall, the results suggest that, while statistically significant, climate change will have a negligible effect on the population distribution of New Zealand at the regional level.

Keywords

climate change
internal migration
gravity model
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JEL Classification

J11; Q54; R23

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1. INTRODUCTION

Climate change is widely considered to be one of the greatest challenges currently facing the global community, and the economic and social consequences of a changing climate are well recognized (see, for example, Stern 2007 and Garnaut 2011). In its summary for policy-makers, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) notes a number of impacts of future climate change on ‘human systems’, including increases in heat-related mortality offset by decreases in cold-related mortality, changes in the distribution of some waterborne illnesses and disease vectors, and negative outcomes for livelihoods, especially for the poor (IPCC 2014). IPCC (2014, p.6) also notes that ‘People who are socially, economically, culturally, politically, institutionally, or otherwise marginalized are especially vulnerable to climate change and also to some adaptation and mitigation responses’.

The future effects of climate change will not only be felt globally, but will differ in their effects at the local level. This will change the distribution of suitable areas for human habitation, with some areas becoming less suitable while others become more suitable. These local impacts include reductions in freshwater availability and quality (Hanjra and Qureshi 2010 and Jiménez Cisneros *et al.* 2014), negative impacts on crop yields and food security (Porter *et al.* 2014 and Schmidhuber and Tubiello 2007), sea level rise and coastal inundation (Strauss 2013 and Wong *et al.* 2014), increased rainfall intensity leading to more frequent and widespread flood events (Hinkel *et al.* 2013; Nicholls *et al.* 2011; Pall *et al.* 2011), and high or increasing vulnerability to climate-related extremes (IPCC 2014).

Given these local impacts of climate change, it is likely that the future spatial distribution of population will be affected. For instance, changes in the average and/or variability in temperature and/or rainfall may lead to changes in economic opportunity (both positive and negative) that induce migration (both international and internal). Migration may also result from an increasing incidence and severity of natural disasters, or sea level rise reducing the availability of coastal land. Indeed, migration is expected to be one of the channels through which people respond or adapt to climate change (Dell *et al.* 2014), especially for communities where the ability to adapt to climate change *in situ* is limited (Adamo, 2010 and de Sherbinin *et al.* 2011). However, it is likely that any impacts of climate change on the population size and distribution will be lessened by adaptation measures undertaken by governments or by individuals or families.

Despite the early acknowledgement of some (even moderate) likely impacts of climate change on migration (for example, see Hugo, 1996), and the expectation that changes in the spatial distribution of population will result, surprisingly little empirical research has been conducted into the sub-national demographic impacts of climate change (see the following section for a brief review). The IPCC Fifth Assessment Report collates and synthesizes the most relevant literature on the impacts of climate change, and yet the demographic projections that were prepared for each Shared Socioeconomic Pathway (SSP) do not themselves incorporate any climate feedbacks (Samir *et al.* 2013, 2015). That is, in those demographic projections international migration between countries (which is likely to be one channel through which climate change will affect population numbers and distribution globally) is assumed to not be affected by the changing climate. Similarly, to date no national statistical agency has incorporated the impacts of climate change explicitly into their official demographic projections.[1]

This lack of inclusion of climate change into demographic projections may simply reflect an acknowledgement that any impacts of climate change are likely to be small and highly uncertain given the possibility of adaptation measures. For instance, Cameron (2013, p.134) reviewed the recent literature on the demographic implications of climate change for New Zealand, and noted that: 'climate change is unlikely to greatly affect fertility rates, and will likely have a small but significant effect on mortality rates. The effect on international migration will largely depend on future government policy with respect to in-migration, but regardless migration from the Pacific will likely increase, both in absolute terms and as a proportion of total migration. Changes in the pattern of internal migration are also likely, as climate change will differentially affect the various regions in New Zealand'. He concluded that the overall impact of climate change on the population of New Zealand was likely to be small. Similarly, in a review of climate change impacts on the demography of Australia, Hugo (2011, p.65) noted that 'climate change is unlikely to cause massive rapid dislocation of population and population redistribution'. Fielding (2011) also concluded that there would be a lack of major population redistribution for the United Kingdom resulting from climate change.

Despite these assertions of limited impacts of climate change on the population distribution within countries, there remains a lack of clear empirical evidence. This paper seeks to fill the gap in understanding the sub-national impacts of climate change on the population distribution, using a case study of the sixteen regions of New Zealand (Figure 1 shows these regions in different colours). New Zealand (total 2013 population of 4.44 million) is split into regions that range in population size from Auckland (1.49 million) to West Coast (33,000). New Zealand presents a useful case study for the impacts of climate change at the local level because, despite being a small country in population size, it is large enough geographically to experience significant climate variation. For instance, the annual average daily maximum temperature in each region[2] for 1991-1995 ranged from 19.5 degrees Celsius in Northland, to 14.4 in Southland, while annual precipitation for 1991-1995 ranged from

[1] See Rees *et al.* (2010), however, for an application that incorporates climate change into the migration component of a population projection model for NUTS2 regions in the European Union.

[2] These averages are population-weighted. See later in this paper for details.

725mm in Canterbury to 2933mm in the West Coast. The regions are also projected to experience the effects of climate change differentially (see, for example, Mullan *et al.* 2008). Moreover, New Zealand also experiences substantial internal migration flows that are much larger than international migration flows, and it is internal migration flows that are the main focus of this paper.

Figure 1: New Zealand Regions

Source: Wikimedia Commons.

Specifically, we estimate the impact of climate variables on internal migration dynamics using a gravity model specification, and then use the gravity model as part of a multi-regional population projection model to evaluate the impact of different climate change scenarios in the period to 2100. Projecting future populations not only requires estimates of future internal migration, but also international migration, as well as fertility and mortality (or survivorship). For international migration, we calibrate our model to replicate the international projections conducted by IIASA for the IPCC (Samir *et al.* 2013), which as noted above do not account for changes in climate. To concentrate our research on the internal migration impacts, we follow Rees et al. (2010) and assume that fertility and mortality are unaffected by changes in local climate.[3] This means that our results can be interpreted as the observed and projected impacts of climate change on the population distribution, working solely through the internal migration channel.

The remainder of the paper proceeds as follows. Section 2 briefly reviews the literature on the effects of climate change on migration, with a particular focus on internal migration. Section 3 describes the data and methods used in this paper, and Section 4 presents the results of the estimation of the gravity model and the resulting projections to 2100. Section 5 further discusses the implications of the results and concludes the paper.

2. INTERNAL MIGRATION AND CLIMATE

Before considering migration, it is worth clarifying what we mean when we refer to the climate. Dell *et al.* (2014) notes an important distinction between ‘climate variation’, being the long-run variation in the distribution of outcomes (for example, rainfall, sunlight hours) and ‘weather variation’, being short-run temporal variation in those outcomes. This distinction is important, because some studies of the effect of climate on migration use climate variation (for example, mean annual daily temperature, annual total precipitation) as the key variable/s of interest, while others use weather variation (for example, frequency and/or severity of extreme weather events). While adopting an approach that relies on exogenous weather shocks (such as extreme weather events) is attractive because of the ability to identify the causal impacts of climate on migration (Dell *et al.* 2014), Piguet *et al.* (2011) argue that slow-onset climate change is more likely to result in long-term migration than extreme events, in part because those affected by extreme events can return home after the event has passed. Moreover, an understanding of the effects of extreme events on migration is less useful when projecting the *future* impacts of changes in the distribution of weather over longer timescales, because such a projection would necessarily require scenarios based on the timing and intensity of highly uncertain extreme weather events.

[3] While there may be impacts of climate change on mortality (but probably not on fertility), and these impacts may be different for different regions, the direction and magnitude of these impacts are not clear.

There are many models of migration decision-making. The simplest economic model suggests that potential migrants evaluate the costs and benefits of remaining in their current location against the costs and benefits of other locations, taking into account the costs (both financial and otherwise) of moving location (see, for example, Roback 1988). If some other location provides a greater lifetime net benefit (difference between benefits and costs), then the person will move to that location. Klaiber (2014) notes two hypotheses for the effects of climate on migration on such a model: (1) through changes in economic opportunities; and/or (2) through changes in climate amenity. Following Lee (1966), in the simple model climate and weather variables might act as push factors from the origin (for example, lower rainfall reducing agricultural incomes in rural areas, or increasing flood events raising the insurance costs of living in flood-prone areas) or as pull factors from the destination (for example, greater amenity benefits in areas with generally sunnier and more settled weather). Thus, there is the potential for changes in climate in both origin and destination areas to affect the magnitude and direction of migration flows, with areas with more favourable 'climate bundles' experiencing more in-migration and less out-migration than similar areas with less favourable 'climate bundles' (Graves 1980). These effects hold even if climate amenity or disamenity is not the primary motivation for migration (Partridge 2010).

Much of the literature on migration and either weather or climate has focused on international migration (see, for example, Beine and Parsons 2015, Backhaus *et al.* 2015 and Beine *et al.* 2015). Much less attention has been paid to climate's impact on internal migration, despite there being nearly four times as many internal migrants worldwide compared with international migrants (IOM 2015),[4] and the great majority of climate-related migration occurs within countries rather than between countries (Adamo and Izazola 2010 and Warner *et al.* 2009). In an early contribution, Mueser and Graves (1995) investigated inter-State migration in the United States over the period 1950-1980, using cross-sectional regression models for each decade. They found that higher average January (winter) temperatures and lower average July (summer) temperatures are positively associated with the net migration rate in each decade. Similarly, Rappaport (2007) found that a number of climate variables affected the county-level annual growth rate of population density in the United States over the period 1970-2000, treated as a single cross-section. Specifically, he found that warmer winter temperatures had a significant positive effect on population growth, while both higher average July heat index (a combination of temperature and humidity) and higher relative humidity had significant negative effects on population growth. Moreover, the magnitude of these effects was relatively large, with an increase in winter temperature from one standard deviation below to one standard deviation above its sample mean being associated with 1.3% faster annual population growth. Rappaport also found that the effects

[4] The IOM World Migration Report 2015 notes estimates of 232 million international migrants, and 740 million internal migrants.

were most significant for older people, which are similar to the more recent findings of Biddle (2012).

Poston *et al.* (2009) investigated the effect of climate variables on in-migration rates, out-migration rates, and net migration rates for US states over the period 1995-2000. Rather than the climate variables entering the model individually, they first reduced the dimensionality of the climate variables using factor analysis, identifying three statistically independent factors that they labelled ‘temperature’, ‘humidity’, and ‘wind’. In a cross-sectional regression analysis, they found that all three climate variables were statistically significantly associated with out-migration, that temperature and humidity, but not wind, were statistically significantly associated with net migration, and that only humidity was statistically significantly associated with in-migration rates. Focusing on the significant gross migration results, lower humidity was associated with both higher in-migration and higher out-migration, while higher temperature and lower wind were associated with higher out-migration. In their analysis, the climate variables were the most significant predictors of migration, more so than economic variables. However, all of these studies treated the data as cross-sectional, which fails to account for unobserved time-invariant differences between areas, and also does not account for the time-varying nature of the climate variables that are included in the model.

Rather than looking at longer-run climate changes, some studies have focused on the severity or frequency of extreme weather events, and their impact on internal migration. For instance, Hornbeck (2012) studied the 1930s American Dust Bowl and found that this extreme erosion event had large and persistent effects on population size, with larger population declines in counties that experienced more erosion. Gray and Mueller (2012) investigated the impact of flooding (and crop failures) on internal migration in Bangladesh, using a longitudinal dataset from 1994-2010 and event history analysis. They found that moderate flooding (compared with low flooding) resulted in a shift from long-distance to local mobility, while the impacts of severe crop failures had large positive effects on mobility. However, these event studies and similar studies of extreme weather events (for example, Boustan *et al.* 2012 and Ouattara and Strobl 2014) provide little guidance as to the future impacts of long-run slow-onset climate changes.

Panel data analyses of climate change and internal migration have only recently begun to be undertaken, to overcome issues of unobserved heterogeneity that may otherwise drive the results (Beine and Parsons 2015). Feng *et al.* (2012) investigated the effect of agricultural productivity (which will be affected by climate) on migration for rural Corn Belt counties in the U.S., using data from 1970-2009. They found a statistically significant relationship between climate-driven changes in crop yields changes and net outmigration and, with a 1% decrease in yields associated with a 0.17% increase in net out-migration. However, their analysis considers agricultural productivity as the only channel through which climate change will act,[5] and is necessarily only applicable to rural areas. Marchiori *et al.* (2012) investigate the impact of weather anomalies (standardised deviations from mean values for weather variables) on internal and international net migration in sub-Saharan Africa, using panel data for 1960-2000 and instrumental variables analysis that accounts for the endogeneity of urban populations. They find that temperature and rainfall anomalies caused a total net displacement of 5 million people over the 1960-2000 period. However, their use of net migration as the dependent variable is potentially problematic, particularly if (as other studies noted above have found) in-migration and out-migration are affected differently by climate variables.

Despite the widespread use of the gravity model for understanding gross migration flows between countries and between regions within countries (Poot *et al.* 2016 and Ramos 2016), to date there have been few applications of the gravity model that include climate variables. Notable exceptions include Beine and Parsons (2015) and Backhaus *et al.* (2015), but both use climate variables exclusively to investigate international migration. Both studies find robust effects of climate variables within the gravity modelling framework. To the best of our knowledge, no gravity model of internal migration has previously been developed to investigate the impact of climate variables on internal migration. This paper seeks to fill that important gap in the literature.

3. DATA AND METHODS

3.1 Data

Annual data on thirteen climate variables were obtained from the HadGEM2 model (Collins *et al.* 2011), statistically downscaled to a 5 kilometre grid of 'virtual climate stations' for New Zealand for the period 1991 to 2100 (Ministry for the Environment 2016, Tait *et al.* 2016 and Dell *et al.* 2014) refer to data that combines information from ground stations and other inputs with a climate model to estimate weather variables across a grid as 'reanalysis data'. The advantage of using reanalysis data is that it naturally leads to a balanced panel dataset, as there are no missing weather station data.

Raster zonal statistics (in ArcGIS) were used to convert the grid-based climate data into averages for each area unit in New Zealand.[6] Specifically, the climate data (for each climate variable, for each year) was extracted as a raster layer, then each raster cell was converted to a vector point. Points were then interpolated using a spline, which was then

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[5] See Beine *et al.* (2015) for a discussion of four possible channels for the effect of climate on migration.

[6] Area units are the second-smallest geographical area for which Statistics New Zealand produces data, and regions are made up of complete sets of area units. Area units in urban areas are approximately the size of a suburb, with a mean population of about 4500.

resampled to the resolution of the area units raster (to ensure that all area units had values associated with them). Finally, the zonal mean of each climate variable in each year was calculated for each area unit. Population-weighted averages (based on 2013 estimated usually resident populations of each area unit) were used to aggregate the area unit data into annual climate variables for each of the sixteen regions in New Zealand. Population weighting is appropriate since it reflects how strongly the population actually experiences changes in the climate (Dell *et al.* 2014).

Data on migration (both internal and international) were derived from each national Census from 1996 to 2013, based on responses to a question that asked for each respondent's place of residence five years previous.[7] The advantage of this data is that it gives the most complete picture of internal and international migration flows in both directions, i.e. migration flows between each region, and from overseas into each region, are directly computable, while migration flows from each region to overseas (which are not directly observable in the Census data) can be derived as a residual.

In addition, population data for each region were taken from Statistics New Zealand's estimated usually resident subnational populations in each year.[8] This is the best available estimate for the population of each region in each year. Data on inter-regional distances was computed as the straight-line distance between the population-weighted centroid of each region.[9] Alternative specifications of inter-regional distance, including road network distance, are unlikely to have dramatic effects on the estimates from the gravity models, as shown by Alimi *et al.* (2015) and Poot *et al.* (2016).

Summary statistics for the data are presented in Table 1. There are 960 observations, being 240 (16 x 15) inter-regional observations for each of four five-year periods. The migration and population variables are very skewed, which justifies taking natural logs of these variables for analysis.

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[7] The Census of Population and Dwellings is usually held every five years; however, due to the 2010 and 2011 Christchurch earthquakes, the 2011 Census was delayed until 2013. Because the migration data were based on a question that asked for each respondent's place of residence five years previous, this break in the five-year frequency of the Census does not pose a serious issue for the data.

[8] The exception is the population for 1991, where an estimated usually resident population was not available due to a change in population definitions at the time, when only the de facto population was reported. In this case, we took the estimated *de facto* population from the 1991 Census, and scaled it based on the region-specific ratio of *de facto* to *de jure* population from the 1996 Census.

[9] Specifically, the population-weighted centroid was calculated from the 2013 estimated usually resident population of each area unit, and the geographic centroid of each area unit.

Table 1: Summary Statistics

Variable		Mean/ Proportion	Standard Deviation	Minimum	Maximum
M_{ij}	Gross migration flow	1535	2529	1	20089
P_i, P_j	Population	239 817	284 246	31100	1 405 500
D_{ij}	Distance, km	471	287	21.8	1277
η_{ij}	Cook Strait dummy	0.525	0.500	0	1
λ_{ij}	Contiguity dummy	0.188	0.391	0	1
Tmax	Annual average daily max. temperature, Celsius	17.5	1.44	14.3	19.9
Tmin	Annual average daily minimum temperature, Celsius	8.4	1.60	5.4	11.4
MSLP	Daily average mean sea level pressure, hPa	101.3	124.4	101.0	101.6
PE	Daily average potential evapotranspiration, mm	3.69	0.40	2.76	4.58
RH	Daily average relative humidity, %	72.6	2.52	66.2	77.0
SRad	Daily average surface radiation, MJ/m^2	157.0	16.8	126.1	185.7
TD	Daily average dew-point temperature, Celsius	7.95	1.26	5.28	10.3
Rain	Daily average total precipitation, mm	3.58	1.59	1.78	9.46
VP	Daily average water vapour pressure, hPa	1.11	0.09	0.913	1.29
WS10	Daily average wind speed at 10 metres, m/s	3.97	1.15	2.22	6.75
DryDays	Annual days with less than 1mm precipitation	171	28.7	104	219
T0	Annual days with minimum temperature < 0 Celsius	12.9	10.4	0.028	31.7
T25	Annual days with maximum temperature > 25 Celsius	17.2	10.6	0.930	46.0

3.2 Gravity Model Method

We use a gravity model specification to investigate the influence of climate variables on internal migration. The theoretical underpinning of the gravity model is the random utility maximization (RUM) model (Beine and Parsons 2015). The RUM model assumes that people make decisions about migration based on the expected utility they would receive from alternative destinations (or remaining in the origin). The model incorporates both the benefits (which may include the utility from climate amenity value in different destinations) and the costs (which may include the utility foregone from climate amenity value in the origin, and the cost of moving from origin to destination), as well as a random component that captures unobserved individual-specific differences in utility. Assuming a log-normal distribution of the random component leads to a model where the expected migration flows from each origin to each destination depend on the characteristics of the origin (including climate amenity), the attractiveness of the destination (including climate amenity), and the accessibility of the destination from the origin (typically proxied by the distance between them). The standard specification for the gravity model, expressed in log-linear form, is:

$$\ln M_{ij} = \beta_1 \ln P_i + \beta_2 \ln P_j + \beta_3 D_{ij} + \varepsilon_{ij}; i \neq j \qquad (1)$$

where M_{ij} is the gross migration flow from area i (the origin) to area j (the destination), $i,j = 1,2,\ldots R$, P_i and P_j the corresponding population stocks in areas i and j respectively, D_{ij} is the distance between i and j, and ε is an idiosyncratic error term. The gravity model can easily be augmented to account for observed and unobserved time-invariant differences between origins and destinations (see, for example, Lewer and Van den Berg 2008). We initially augment this standard specification in two ways, by including: (1) origin and destination fixed effects; and (2) dummy variables for whether the migration flow crosses the Cook Strait and for whether the two regions are contiguous. Fixed effects are used to account for unobserved, time-invariant differences between the regions (that is, time-invariant push and pull factors that affect migration between regions). The Cook Strait and contiguity dummy variables account for the greater cost of relocation between the islands, and short-distance 'spill-over' migration that would not be adequately captured by the distance variable, respectively. Time fixed effects are not included because they cannot be projected forward and would not be useful in the population projection exercise to follow. The augmented specification therefore is:

$$\ln M_{ij} = \beta_1 \ln P_i + \beta_2 \ln P_j + \beta_3 D_{ij} + \chi_i + \varphi_j + \eta_{ij} + \lambda_{ij} + \varepsilon_{ij}; i \neq j \qquad (2)$$

where χ_i and φ_j are time-invariant origin and destination-specific fixed effects respectively, η_{ij} is a dummy variable indicating whether the migration flow from i to j crosses Cook Strait, and λ_{ij} is a dummy variable indicating whether regions i and j are contiguous. Finally, we further augment the specification by including vectors of climate variables in both the origin and the destination, i.e.

$$\ln M_{ij} = \beta_1 \ln P_i + \beta_2 \ln P_j + \beta_3 D_{ij} + \beta_4 \theta_i + \beta_5 \kappa_j + \chi_i + \varphi_j + \eta_{ij} + \lambda_{ij} + \varepsilon_{ij}; i \neq j \qquad (3)$$

where θ_i is a vector of climate variables in the origin, and κ_j is a vector of climate variables in the destination. Other time-varying control variables (for example, measures of economic output, incomes or jobs) were not included in the model because they may also be related to the climate variables, and would also make the model susceptible to the 'over-controlling' problem (see, for example, Borjas 1999). Moreover, economic variables are notoriously difficult to forecast, so including these variables in the population projection model (see below) would require an economic forecasting model with a great deal of uncertainty in its forecasts.

The model in Equations (2) and (3) may be estimated using a number of different approaches. Poisson pseudo-maximum likelihood (PPML) is increasingly favoured (Santos, Silva and Tenreyro 2010). However, PPML tends to over-weight high-value flows (Ramos, 2016), which would be problematic in our case given the potentially large leveraging effect of flows to and from Auckland (which contains about one-third of the total population of New Zealand, and is more than three times larger than the next-largest region). Instead, we employ a standard panel fixed effects regression model.

To establish the relative importance of each climate variable, we included each of the thirteen climate variables into the gravity model specification, one at a time (for both the origin and destination). The results are summarised in Table A6 in the Appendix. Eight candidate variables were identified for inclusion in the final gravity model specification (mean sea level pressure [destination]; potential evapotranspiration [origin and destination]; relative humidity [destination]; surface radiation [origin and destination]; annual precipitation [destination]; wind speed at ten metres [origin and destination]; number of days with minimum temperature below zero degrees Celsius [origin and destination]; and number of days with maximum temperature above 25 degrees Celsius [destination]). Backward stepwise regression was then used to reduce the number of climate variables in the model, retaining those with the highest level of statistical significance. This process was used to reduce the problem of over-fitting by using a more parsimonious model.

3.3 Population Projection Method

A cohort-component population projection model (CCM) relies on projections of three components: (1) fertility (births); (2) mortality (deaths) or survivorship; and (3) migration (internal and international). Following Cohen *et al.* (2008), we embed the gravity model within a multi-region CCM (Cameron and Poot 2014). The key difference is that Cohen et al. (2008) used the gravity model to estimate international migration, whereas our gravity model projects internal migration. We use two different gravity model specifications within the projections model, based on the two gravity models presented in Equations (2) and (3).

For projections of fertility (total fertility rates) and mortality (life expectancy), Statistics New Zealand sub-national projections were used. Based on an earlier literature review (Cameron 2013), we established that it was unlikely that climate change would have significant impacts on either fertility or mortality, and that the impact on international migration flows was uncertain but heavily reliant on the future political climate.

The projected values of total international migration flows (immigration and emigration) were taken from the IIASA global projections for Shared Socioeconomic Pathway 3 (SSP3) used for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Samir and Lutz 2015 and Samir *et al.* 2013). A Shared Socioeconomic Pathway (SSP) is defined as a scenario that links a climate path to a range of human development pathways (Burkett 2014). The goal of SSPs is to characterize a range of futures as a reference for climate change analysis (O'Neill *et al.* 2012). We use SSP3 as it can be considered a 'mid-range' scenario.

We then re-calibrated the CCM model to reproduce as closely as possible the IIASA projection for New Zealand as a whole, by adjusting immigration numbers in each five-year period to ensure that the total population from our model closely matched the IIASA national projection. The resulting re-calibrated projection matches the IIASA projection for each five-year period to within 0.03%. As noted previously, the IIASA projections are not affected by climate variables. Thus, the main mechanism through which climate change will affect the New Zealand population (number and distribution) is through changes in internal migration dynamics.

Finally, separate projections were run under SSP3 for each of the four Representative Concentration Pathways (RCP2.6; RCP4.5; RCP6.0; and RCP8.5). The four Representative Concentration Pathways (RCPs) represent a range of trajectories of greenhouse gas concentrations and associated climate change, and are labelled by their approximate radiative forcing reached by the end of the 21st Century (van Vuuren *et al.* 2011). The RCPs are independent of the SSPs, such that any combination of SSP and RCP is valid for forecasting purposes, though some combinations may be more consistent than others.

4. RESULTS

Table 2 presents the resulting estimations of Equations (1)-(3). In all cases the models explain an overwhelming proportion of the variation in internal migration, with adjusted R^2 values of over 0.83 for Model (1) and nearly 0.95 for Models (2) and (3). The addition of fixed effects and the Cook Strait and contiguity dummy variables increases the R^2 value markedly, while the climate variables have a much smaller effect. As expected, all variables in the standard gravity model are highly statistically significant, with coefficients mostly in the expected direction. The exception is the population in the destination in Models (2) and (3), which has a negative and highly statistically significant coefficient, suggesting that areas with larger populations attract fewer migrants. However, this negative coefficient on one of the population variables appears to be characteristic of the gravity model with origin and destination fixed effects (for example, see Cameron and Poot 2014 and Backhaus *et al.* 2015), and as we demonstrate below, it does not appear to adversely affect the population projections that include these models.

Table 2: Gravity Model Results

Variable	Model (1)	Model (2)	Model (3)
lnP_i	0.860***	0.929***	1.352***
	(0.186)	(0.188)	(0.200)
lnP_j	0.844***	-0.859***	-0.498**
	(0.186)	(0.188)	(0.195)
lnD_{ij}	-0.919***	-0.782***	-0.782***
	(0.027)	(0.032)	(0.032)
Contiguity dummy	-	0.157***	0.157***
		(0.044)	(0.043)
Cook Strait dummy	-	-0.650***	-0.650***
		(0.029)	(0.029)
$MSLP_j$	-	-	0.0007***
			(0.0002)
$SRad_i$	-	-	-0.012**
			(0.005)
$WS10_j$	-	-	-0.299**
			(0.133)
Adj. R^2	0.831	0.946	0.948

Note: Origin and destination fixed effects in Models (2) and (3) not shown; robust standard errors in brackets below coefficients; n=960; *** p<0.01; ** p<0.05; * p<0.1.

The most parsimonious model for Equation (3) includes three statistically significant climate variables: (1) mean sea level pressure in the destination ($MSLP_j$); (2) surface radiation in the origin ($SRad_i$); and (3) wind speed at ten metres at the destination ($WS10_j$). The sign of the effects suggest that mean sea level pressure (MSLP) is a positive pull factor, with migrants attracted to areas with higher MSLP; surface radiation is a negative push factor, with migrants less likely to move away from areas with higher surface radiation (for example, areas with more sunlight hours); and wind speed is a negative pull factor, with migrants preferring to avoid moving to areas that are windier.

All of the statistically significant climate effects seem intuitively plausible. However, the small effect of their inclusion on the R^2 would rightly make one wonder whether their effects are economically meaningful. That is, are these variables statistically significant but of magnitudes that have no practical significance? To test this, we first compare two different CCM models: one that includes the gravity model from Equation (2), and one that includes the gravity model from Equation (3). The climate data comes from the RCP6.0 scenario, representing a mid-range scenario.

Table 3 presents the results (in terms of total regional populations) comparing the two alternative CCM models (more complete data are available in Tables A1-A5 in the Appendix). The fertility, mortality, and international migration assumptions are identical between these two models, so the only first-order difference between them is in the internal migration flows.[10] The total New Zealand population is slightly higher when the climate variables are included in the model, because this causes more migration flows to regions that have higher fertility (particularly Northland). Overall, and for every region, the population increases between 2013 and 2040, before decreasing to 2070 and 2100. This is largely to be expected, as the total New Zealand population projected by IIASA (and used to calibrate the international migration for these projections) also increases to a peak in 2045 before declining through to 2100 (Samir *et al.* 2013).

Table 3: CCM Population Projection Results Excluding and Including Climate Variables (000s)

Region	Population	Model (2)			Model (3), RCP6.0		
	2013	2040	2070	2100	2040	2070	2100
Northland	165	178	175	148	183	181	153
Auckland	1,493	1,761	1,627	1,284	1,745	1,609	1,297
Waikato	425	487	485	406	494	495	416
Bay of Plenty	280	325	322	274	331	329	281
Gisborne	47	53	51	43	53	53	44
Hawke's Bay	158	170	165	140	171	168	143
Taranaki	114	119	112	94	120	114	97
Manawatu-Wanganui	231	253	242	200	253	245	203
Wellington	487	549	501	402	547	504	399
Tasman	49	52	48	40	53	48	41
Nelson	49	55	52	43	55	52	44
Marlborough	45	50	48	41	51	48	41
West Coast	33	34	31	26	34	31	26
Canterbury	563	625	576	472	625	579	473
Otago	209	232	212	171	235	215	174
Southland	96	90	73	61	90	71	61
Total New Zealand	4,442	5,034	4,718	3,845	5,040	4,743	3,890

The projected populations for most regions are largely unaffected by the inclusion of the climate variables, remaining within 2.5 percent of those that exclude climate variables throughout the projection period to 2100. The exceptions are Taranaki, which has a population over 3 percent higher in 2100 when the climate variables are included, and Northland, which has a population about 3.4 percent higher in 2070 and 2.8 percent higher in 2100 when the climate variables are included. Figures 2 and 3 further illustrate the comparison between the models excluding and including climate variables for the Northland and Taranaki regions respectively. Figure 2 makes it clear that including the climate

[10] To the extent that internal migration leads some migrants to move to areas with higher (lower) fertility rates and lower (higher) mortality rates, this will lead to second (and higher) order effects that increase (decrease) the regional (and total New Zealand) populations.

variables has a substantial effect on the total population of Northland and that effect reduces over time, whereas in Figure 3 the opposite is true for Taranaki, with the climate-variable-inclusive model diverging steadily away from the model excluding climate variables.

Figure 2: Population Projection Scenarios for Northland Excluding and Including Climate Variables

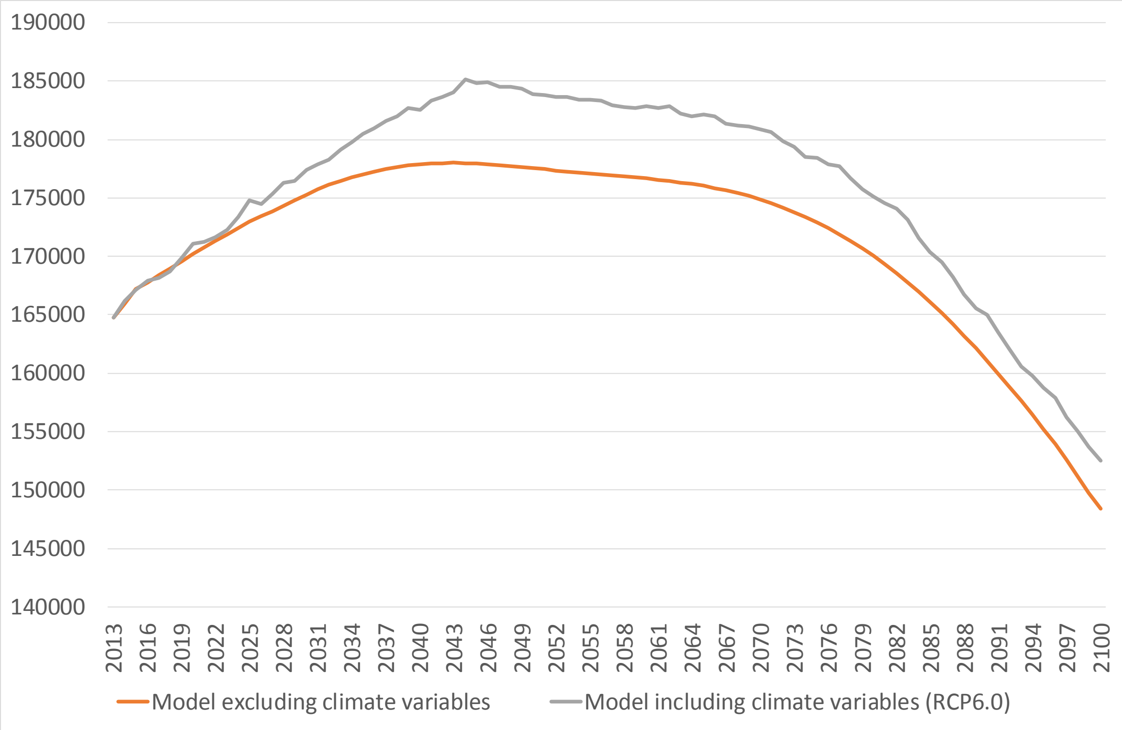

Figure 3: Population Projection Scenarios for Taranaki Excluding and Including Climate Variables

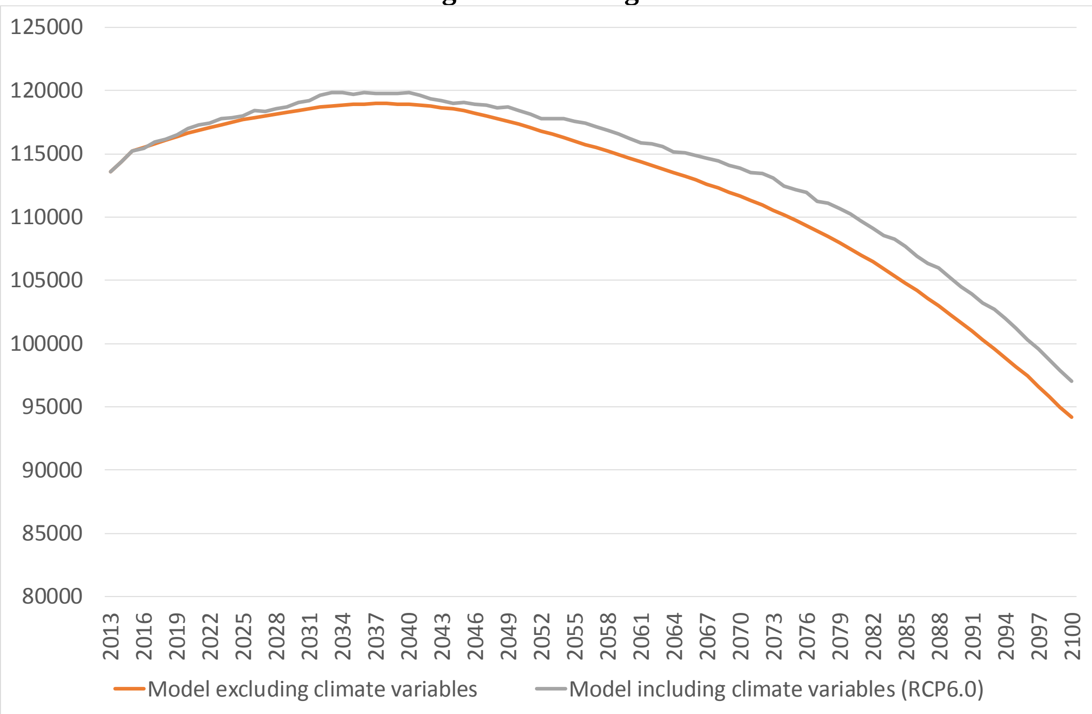

Table 4 summarises the population projection results for each of the four RCP scenarios (more complete data are available in the Appendix). Recall that the only difference between these scenarios is the projected values of the climate variables. The results demonstrate that the choice of climate change scenario mostly has little effect on the projected populations for most regions. Regardless of RCP, all regions show a similar pattern of initial population growth, followed by later population decline. The differences in the population projections, moving from RCP2.6 to RCP8.5, are not monotonic. This is because the climate changes themselves are not necessarily monotonic, and are not constant across regions. The impact of future climate change on total population appears to be greatest (in relative terms) for Southland (where the Coefficient of Variation between the four scenarios is 2.5% in 2100), Northland (1.7%), and Tasman (1.7%).

Figure 4 further illustrates the differences between RCP scenarios for the Southland region. The four RCP scenarios are almost indistinguishable from each other until after 2040. Interestingly, from 2040 the RCP2.6 scenario results in the highest population for Southland (or rather, the lowest depopulation), and from the 2060s the RCP4.5 scenario is about the median of the four scenarios. In contrast, the RCP6.0 scenario is initially very similar to the RCP8.5 scenario, before switching in the 2070s and 2080s to be much more similar to the RCP2.6 scenario. However, overall there is a common trend to all the scenarios and there is little to differentiate them from each other (even more so for other regions), illustrating an overall lack of impact of climate change on the population distribution for New Zealand.

Figure 4: Population Projection Scenarios for Southland, By RCP Scenario

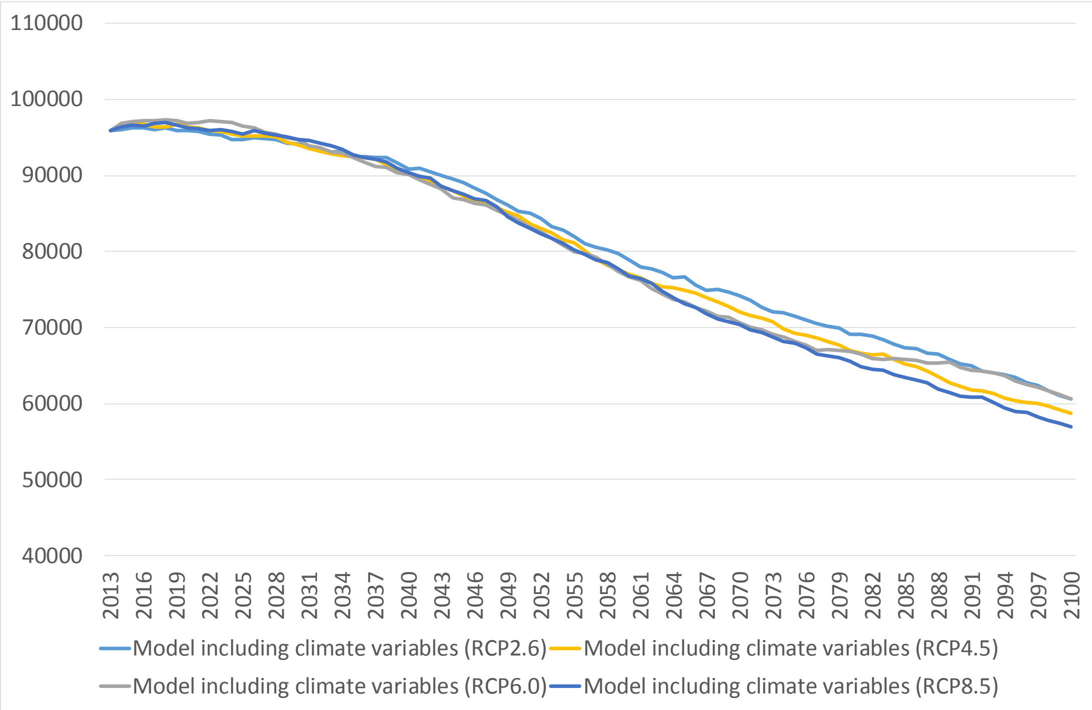

Table 4: CCM Population Projection Results for Each RCP Scenario (000s)

Region	Popn	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
	2013	2040	2070	2100	2040	2070	2100	2040	2070	2100	2040	2070	2100
Northland	165	178	180	151	180	180	153	183	181	153	182	185	158
Auckland	1,493	1,722	1,589	1,279	1,737	1,605	1,291	1,745	1,609	1,297	1,741	1,621	1,310
Waikato	425	492	491	410	495	494	414	494	495	416	493	494	413
Bay of Plenty	280	331	329	277	333	329	280	331	329	281	331	331	282
Gisborne	47	54	53	44	53	53	44	53	53	44	53	53	45
Hawke's Bay	158	175	171	145	174	169	143	171	168	143	171	169	146
Taranaki	114	120	113	96	120	114	97	120	114	97	120	114	97
Manawatu-Wanganui	231	258	246	203	254	245	202	253	245	203	254	241	198
Wellington	487	552	503	404	545	502	405	547	504	399	548	491	393
Tasman	49	54	50	42	53	48	41	53	48	41	53	48	40
Nelson	49	57	53	45	56	52	44	55	52	44	56	53	45
Marlborough	45	51	49	42	50	49	41	51	48	41	51	48	41
West Coast	33	35	32	27	34	31	26	34	31	26	34	31	26
Canterbury	563	631	586	484	630	581	475	625	579	473	627	580	470
Otago	209	238	220	177	235	215	172	235	215	174	236	214	170
Southland	96	91	74	61	90	72	59	90	71	61	90	70	57
Total New Zealand	4,442	5,038	4,740	3,888	5,039	4,739	3,887	5,040	4,743	3,890	5,040	4,742	3,890

5. DISCUSSION AND CONCLUSIONS

Significant concern has been raised about the impact of climate change on the population, including the suggestion of millions of future 'climate refugees' (see, for example, Myers 2002). However, we find no evidence to support large migration movements internally for New Zealand. The overall impact of the full range of considered future climate change scenarios (albeit anchored to a single Shared Socioeconomic Pathway) is minimal, with all scenarios showing very similar trajectories. These differences in the projected regional populations are small even though in the gravity models of migration the effects of three climate variables are statistically significant. This suggests that other determinants of migration are much more salient for internal migrants than changes in climate. Moreover, the differences between the climate change scenarios are likely to be much smaller than the uncertainty in the projected regional populations (see, for example, Cameron and Poot 2011).

This is not to say that climate change will not have important and substantial effects at very localised levels. For instance, sea level rise and coastal inundation will lead to a need for costly mitigation efforts, or coastal residents will become displaced. However most, if not all of the localised displacement of people due to climate change will likely be handled locally, and the size of migration flows *across regional borders* arising from climate change are likely to be very small. This makes sense, given that longer-distance migration would entail job dislocation and other costs for the migrants, which could be reduced by remaining closer to their origin. However, while long-run changes in climate may have little impact, increasing incidence or severity of extreme weather events (which were not investigated in this study) could create permanent population shocks that disrupt the existing population distribution, especially at the local level, as happened for the 2010 and 2011 Christchurch earthquakes.

Our study has a number of limitations. First, this study relies on reanalysis climate data. These data rely on interpolation, and different interpolation methods will produce different estimates (Dell *et al.* 2014). This is likely to be a greater issue for some climate variables like precipitation, where spatial variation is greater. Second, one of the assumptions of the random utility model underlying the gravity model is that the attractiveness of a destination is not supposed to be affected by migration, which may not always be the case in reality. Additional migration to an area might open up job opportunities for other migrants, for instance.

Finally, one may be concerned that using the historical relationship (over 22 years) between climate and internal migration to project forward 87 years is invalid. However, we note that recent experience of climate change is similar to that predicted by climate models. Given that these climate trends have been forecast to continue along a similar trend, then previous experience provides relevant data to understand the effect of future climate change.

The projected impact of climate change on the regional population distribution in New Zealand is very small, relative to population size and underlying population change. These results differ from those in developing countries (see, for example, Marchiori *et al.* 2012), where significant impacts were projected. This should not come as a surprise though, as high-income countries are likely to be better able to adapt and mitigate the impacts of climate change than poor vulnerable states (IPCC 2014). Others have concluded that the extent of internal migration as a result of climate change depends on the quality of governance (Sharma and Hugo 2009), and so for Western democracies with strong governance structures such as New Zealand, it is reasonable to expect the effects of climate change on internal migration to be relatively minor.

New Zealand has a number of features that make this case study attractive and potentially relevant to other countries, including significant climate variation across the country and high extant levels of internal migration. The negligible impacts of climate change on the population distribution at the regional level for New Zealand supports the earlier assertions by Fielding (2011) on the lack of any impact of climate on internal migration in the U.K. Our results also suggest that there may be similar null effects for counties in the U.S., or regions in Europe, for instance. However, this could be confirmed by conducting a similar exercise for those countries.

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Appendix

Table A1: CCM Population Projection Results for Model Excluding Climate Variables (000s)

Year	2013	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Model Excluding Climate Variables																		
Northland	165	170	173	175	177	178	178	178	177	177	176	175	173	170	166	161	155	148
Auckland	1,493	1,638	1,694	1,727	1,748	1,761	1,765	1,758	1,739	1,709	1,671	1,627	1,578	1,524	1,465	1,405	1,344	1,284
Waikato	425	449	462	472	480	487	491	493	493	492	490	485	478	468	456	441	424	406
Bay of Plenty	280	298	308	315	321	325	327	328	328	327	325	322	318	312	305	296	286	274
Gisborne	47	49	50	51	52	53	53	53	53	52	52	51	51	50	48	47	45	43
Hawke's Bay	158	163	166	168	170	170	170	170	169	168	166	165	163	160	156	152	146	140
Taranaki	114	117	118	118	119	119	118	117	116	115	113	112	110	108	105	102	98	94
Manawatu Wanganui	231	241	246	249	252	253	253	252	250	248	246	242	238	232	225	217	209	200
Wellington	487	521	535	543	548	549	548	544	536	526	514	501	487	471	455	437	419	402
Tasman	49	51	51	52	52	52	52	51	50	49	48	48	47	46	45	44	42	40
Nelson	49	52	53	54	55	55	55	55	54	53	52	52	51	50	48	47	45	43
Marlborough	45	47	48	49	50	50	50	50	50	49	49	48	47	46	45	44	43	41
West Coast	33	34	34	34	34	34	34	33	33	32	32	31	31	30	29	28	27	26
Canterbury	563	597	610	619	624	625	624	618	610	600	588	576	562	546	529	510	491	472
Otago	209	222	228	231	233	232	231	229	226	222	218	212	207	200	193	186	178	171
Southland	96	97	96	94	92	90	88	84	81	78	75	73	71	69	67	65	63	61
Total New Zealand	4,442	4,747	4,873	4,955	5,007	5,034	5,037	5,013	4,964	4,897	4,815	4,718	4,608	4,481	4,337	4,180	4,015	3,845

Table A2: CCM Population Projection Results for RCP2.6 (000s)

Year	2013	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Northland	165	170	173	174	178	178	179	181	182	183	181	180	178	175	169	164	157	151
Auckland	1,493	1,629	1,680	1,711	1,725	1,722	1,723	1,716	1,699	1,673	1,633	1,589	1,552	1,504	1,449	1,394	1,337	1,279
Waikato	425	450	463	476	484	492	497	499	500	498	496	491	485	474	461	445	429	410
Bay of Plenty	280	300	309	318	325	331	333	335	334	333	331	329	324	317	310	300	289	277
Gisborne	47	49	51	51	53	54	54	54	54	54	53	53	52	51	49	48	46	44
Hawke's Bay	158	164	168	170	173	175	175	176	175	175	173	171	169	165	161	157	151	145
Taranaki	114	117	118	119	119	120	121	119	118	117	116	113	111	109	106	103	100	96
Manawatu Wanganui	231	243	248	252	254	258	259	256	254	251	250	246	240	235	229	220	212	203
Wellington	487	524	538	543	548	552	551	543	533	521	513	503	486	471	454	437	421	404
Tasman	49	51	52	53	54	54	54	53	52	51	51	50	49	48	47	46	44	42
Nelson	49	52	54	55	56	57	57	56	56	55	54	53	52	51	50	49	47	45
Marlborough	45	48	49	50	51	51	51	51	51	50	50	49	48	47	46	45	44	42
West Coast	33	34	35	35	35	35	35	34	34	33	32	32	31	31	30	29	28	27
Canterbury	563	596	611	621	628	631	629	627	619	610	599	586	572	557	540	522	503	484
Otago	209	223	229	234	236	238	237	235	233	229	225	220	214	207	201	193	184	177
Southland	96	96	95	94	92	91	89	85	82	79	77	74	72	69	67	65	63	61
Total New Zealand	4,442	4,747	4,874	4,956	5,010	5,038	5,043	5,021	4,975	4,911	4,832	4,740	4,634	4,510	4,370	4,217	4,056	3,888

Table A3: CCM Population Projection Results for RCP4.5 (000s)

Year	2013	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Northland	165	172	175	177	180	180	182	181	181	182	182	180	179	176	172	168	161	153
Auckland	1,493	1,633	1,683	1,708	1,729	1,737	1,742	1,733	1,711	1,682	1,646	1,605	1,559	1,511	1,458	1,405	1,347	1,291
Waikato	425	451	464	477	486	495	499	503	504	502	498	494	485	477	462	448	432	414
Bay of Plenty	280	301	310	320	327	333	335	336	336	334	332	329	325	320	313	304	293	280
Gisborne	47	49	51	52	53	53	54	54	53	54	54	53	52	51	50	48	46	44
Hawke's Bay	158	164	168	171	172	174	174	173	172	172	171	169	168	164	161	156	150	143
Taranaki	114	117	118	119	119	120	119	119	118	117	116	114	113	110	108	104	101	97
Manawatu Wanganui	231	242	247	251	252	254	253	254	254	251	248	245	240	234	227	218	210	202
Wellington	487	519	534	544	545	545	545	540	535	527	515	502	489	472	457	439	421	405
Tasman	49	51	52	53	53	53	52	52	51	50	49	48	48	47	46	44	42	41
Nelson	49	52	54	55	55	56	56	55	55	54	53	52	52	51	49	48	46	44
Marlborough	45	48	49	50	50	50	50	50	50	50	49	49	48	47	46	44	43	41
West Coast	33	34	35	35	34	34	33	33	33	32	31	31	31	30	29	28	27	26
Canterbury	563	595	610	620	627	630	628	623	613	604	593	581	567	551	533	514	495	475
Otago	209	223	230	234	235	235	234	231	228	224	220	215	209	202	194	186	178	172
Southland	96	96	95	94	93	90	87	85	81	77	75	72	69	67	65	62	60	59
Total New Zealand	4,442	4,747	4,874	4,957	5,010	5,039	5,044	5,021	4,975	4,911	4,832	4,739	4,633	4,510	4,369	4,215	4,054	3,887

Table A4: CCM Population Projection Results for RCP6.0 (000s)

Year	2013	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Northland	165	171	175	177	180	183	185	184	183	183	182	181	178	175	170	165	159	153
Auckland	1,493	1,634	1,684	1,712	1,734	1,745	1,745	1,734	1,716	1,689	1,652	1,609	1,567	1,513	1,460	1,405	1,352	1,297
Waikato	425	451	466	479	488	494	498	502	503	503	500	495	488	479	467	452	434	416
Bay of Plenty	280	300	311	321	327	331	334	335	335	333	332	329	325	319	312	303	293	281
Gisborne	47	49	51	52	53	53	54	54	54	53	53	53	52	51	49	47	46	44
Hawke's Bay	158	164	166	169	170	171	172	172	172	171	169	168	166	164	159	155	150	143
Taranaki	114	117	118	119	120	120	119	118	118	116	115	114	112	110	108	104	101	97
Manawatu Wanganui	231	242	247	251	252	253	253	253	252	250	248	245	240	235	228	221	212	203
Wellington	487	520	532	539	543	547	545	543	535	526	516	504	490	475	457	437	416	399
Tasman	49	51	52	53	53	53	52	52	51	50	49	48	47	47	46	44	43	41
Nelson	49	52	53	55	55	55	56	55	55	54	53	52	51	51	49	48	46	44
Marlborough	45	48	49	49	50	51	51	50	50	50	49	48	48	47	46	44	43	41
West Coast	33	34	35	35	35	34	34	34	33	32	32	31	31	30	29	28	27	26
Canterbury	563	596	609	618	623	625	626	621	612	603	591	579	565	548	530	512	493	473
Otago	209	222	230	234	235	235	233	232	229	225	220	215	209	203	197	189	181	174
Southland	96	97	97	95	92	90	87	84	80	77	73	71	68	67	66	65	63	61
Total New Zealand	4,442	4,747	4,874	4,957	5,011	5,040	5,045	5,023	4,977	4,914	4,835	4,743	4,636	4,513	4,373	4,219	4,058	3,890

Table A5: CCM Population Projection Results for RCP8.5 (000s)

Year	2013	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Northland	165	171	175	177	180	182	184	185	185	185	185	185	181	178	174	170	165	158
Auckland	1,493	1,636	1,686	1,715	1,730	1,741	1,744	1,740	1,720	1,693	1,663	1,621	1,574	1,526	1,472	1,416	1,362	1,310
Waikato	425	451	465	477	487	493	498	501	503	501	499	494	488	478	466	449	432	413
Bay of Plenty	280	300	310	318	325	331	334	335	336	335	333	331	326	320	312	303	293	282
Gisborne	47	49	50	51	52	53	54	54	54	53	53	53	52	51	50	49	47	45
Hawke's Bay	158	164	166	167	170	171	172	172	172	171	170	169	167	164	161	158	152	146
Taranaki	114	117	118	119	120	120	119	118	117	116	115	114	113	111	108	105	101	97
Manawatu Wanganui	231	241	246	250	252	254	253	252	250	248	244	241	237	232	225	216	208	198
Wellington	487	519	535	543	547	548	546	539	530	520	505	491	479	463	448	430	412	393
Tasman	49	51	52	53	53	53	52	52	51	50	49	48	48	47	45	44	42	40
Nelson	49	52	54	55	55	56	56	55	55	54	54	53	52	51	50	48	47	45
Marlborough	45	47	49	50	50	51	51	50	50	49	49	48	47	46	45	44	43	41
West Coast	33	34	34	35	35	34	34	33	33	32	31	31	31	30	29	28	27	26
Canterbury	563	596	609	619	625	627	626	621	614	604	592	580	565	550	531	511	490	470
Otago	209	223	230	235	237	236	234	232	228	224	219	214	208	201	194	186	177	170
Southland	96	96	95	95	93	90	88	84	80	77	73	70	68	66	63	61	59	57
Total New Zealand	4,442	4,747	4,874	4,957	5,011	5,040	5,045	5,022	4,977	4,913	4,834	4,742	4,636	4,513	4,372	4,218	4,057	3,890

Table A6: Gravity Model Coefficients for Climate Variables

Variable	**Coefficient** (Robust Standard Error)
$TMax_i$	-0.045 (0.068)
$TMax_j$	-0.077 (0.068)
$TMin_i$	-0.015 (0.179)
$TMin_j$	0.174 (0.179)
$MSLP_i$	0.0002 (0.0004)
$MSLP_j$	0.0007* (0.0004)
PE_i	-0.612*** (0.183)
PE_j	-0.144 (0.183)
RH_i	0.070*** (0.022)
RH_j	-0.005 (0.022)
$SRad_i$	-0.018*** (0.005)
$SRad_j$	-0.004 (0.005)
TD_i	0.209** (0.082)
TD_j	-0.033 (0.082)
$Rain_i$	0.020 (0.050)
$Rain_j$	-0.108** (0.050)
VP_i	2.461** (1.076)
VP_j	-0.428 (1.076)
$WS10_i$	-0.278** (0.139)
$WS10_j$	-0.365*** (0.139)
$DryDays_i$	-0.001 (0.002)
$DryDays_j$	0.003* (0.002)
$T0_i$	0.028** (0.013)
$T0_j$	0.031** (0.013)
$T25_i$	-0.009*** (0.003)
$T25_j$	-0.004 (0.003)

Notes: All other coefficients not shown. Coefficients for climate variables for both origin and destination are from the same model. Robust standard errors in brackets below coefficients. n=960; $^{***}p$<0.01; $^{**}p$<0.05; $^{*}p$<0.1.