TE TAI ŌHANGA
THE TREASURY

Analytical Note

September 2024

New Zealand demographics and their role in an overlapping generations model

Andrew Binning, Susie McKenzie, Murat Özbilgin and Christie Smith

Analytical Note 24/08

JEL Classifications: J11 Demographic Trends, Macroeconomic Effects, and Forecasts; H55 Social Security and Public Pensions

Key findings

- Like many developed countries, New Zealand's population is ageing. Its population is living longer and fertility rates have fallen, shifting the age composition towards older generations. This change in demographics is expected to continue into the future.
- In this paper, we explore a demographic model based on three core components: fertility rates, survival probabilities, and net migration. We illustrate how varying the assumptions affects the size and age-composition of the long-run population.
- The baseline projections indicate that New Zealand's population could reach approximately 7.5 million beyond 2100, though there is considerable uncertainty about all of the demographic assumptions that underpin such a long-run projection. Given the fertility rates that currently prevail in New Zealand, net migration is likely to play a large role in maintaining New Zealand's population. If current sub-replacement fertility rates continue, New Zealand's population would eventually decline to zero if there was no net migration inflow.
- These demographic trends have implications for many important areas of fiscal policy including superannuation, health, education, and taxation. Population ageing is expected to substantially increase the fiscal cost of superannuation and health care.
- In related analysis, the Treasury is developing an overlapping generations (OLG) model to explore how the demographic trends identified here might influence private behaviour, including participation in the labour force, saving, and capital accumulation. This OLG framework also enables us to consider how private behaviour interacts with different fiscal policies, and how such policies would influence fiscal sustainability and the wellbeing of different generations.

Introduction

Demographics are an important driver of economic and fiscal outcomes. In this Analytical Note we describe some of the properties of Stats NZ's long-run demographic projections and explore their implications using a simple demographic model fitted to match these projections.[1] Our analysis is based on a 'cohort-component method for projecting population', as described in United Nations (2022). Our demographic model has been developed for scenario analysis in conjunction with an overlapping generations (OLG) model under development at the New Zealand Treasury. As well as providing key inputs into the OLG model (namely, population shares and population growth rates), the demographic model allows us to investigate the implications of alternative demographic assumptions for 'population structure' – the age and sex composition of the population.[2]

This paper supports Treasury's four-yearly obligation to provide a statement on the long-term fiscal position. The Treasury's previous statements on the long-term fiscal position identified demographic pressures as a major consideration for the sustainability of fiscal policy in New Zealand.[3]

Like Kudrna et al. (2015), we build a model of demographics based on three core components: fertility, survival probabilities, and net migration (the number of immigrants minus the number of emigrants). Changes in demographics, namely increases in longevity, reductions in fertility, and changes in net migration, have a material impact on economic growth, public revenue, and the fiscal costs of different policies, like the education of new generations, the cost of New Zealand's public health system, and the pay-as-you go superannuation scheme operated to support the wellbeing of the elderly.

At this stage in our research programme we are not specifying the underlying, causal drivers of fertility, mortality and net migration,[4] rather we treat them as exogenous. We adopt a time series perspective to enable us to explore how the age (and sex) characteristics of the population might evolve over the next several hundred years, towards possible steady states.

The age composition of the population is important because people's behaviour changes over the course of their lifetimes, as noted by Modigliani and Brumberg (1954) in their model of life-cycle consumption. Early periods of life are associated with substantial investment in human capital. A period of working-age is associated with strong attachment to the labour force, strong income growth, saving, investment in housing, and further accumulation of capital. Then later in life people's attachment to the labour force weakens and they tend to decumulate assets as consumption exceeds income. At the very end of lifetimes, people may intentionally or unintentionally leave bequests to others, in part reflecting the fact that lifetimes are uncertain.

Changes in age demographics shift the composition of the population at these various life-stages, changing the accumulation of capital, participation in the labour force, and labour productivity. These demographic drivers affect aggregate income, providing a limit on the resources that government can claim through taxation and other revenue mechanisms. The aggregation of producer and consumer behaviour is affected by the population shares, which in turn affects the relative prices that allocate resources and equilibrate demand and suppy through time.

1 We thank Kim Dunstan and Melissa Adams of Stats NZ for providing data on mortality, fertility and net migration and for their feedback on this paper. See Dunstan (2011), Dunstan et al. (2016), Stats NZ (2022), and Salzano et al. (2023) for information about Stats NZ's demographic projections.

2 See Lundquist et al. (2015, p. 93).

3 See https://www.treasury.govt.nz/publications/strategies-and-plans/long-term-fiscal-position.

4 Vollset et al. (2020) and United Nations (2022) develop models that seek to explain the drivers underlying these demographic components.

In a companion paper,[5] we use the Treasury's OLG model to illustrate how this demographic transition affects macroeconomic outcomes. The key demographic features that are important for OLG models are the relative proportions of different generations or agent type, and the growth rate of the population as a whole. Since agents are heterogeneous (with, for example, different assets and different productivities through their lifetimes), the weighted sum of agents matters for the aggregate supply of labour, and for capital per agent, which also matters for production. Overall population growth also matters for macroeconomic outcomes because it determines how much gross investment needs to be undertaken to maintain the current amount of capital per person.

In the first stage of our OLG analysis, we assume a deterministic structure for demographics: all agents in the OLG model understand the current demographic structure and they also understand how the age structure will evolve (e.g., to its eventual steady state). Here we illustrate our main demographic scenario and show how the relative proportions of age cohorts and the overall growth rates change if the underlying demographic assumptions are amended.

Age demographics

New Zealand's economy and its population reflect a complex interplay between decisions to live in New Zealand, decisions to invest, work and save, and decisions to migrate to or from New Zealand. These latter decisions reflect the opportunities abroad and in New Zealand, the amenity value obtained from living here and abroad, the cost of housing, childcare and education, and the financial and non-financial returns from providing labour and capital. While these individual decisions reflect a host of complex factors, national age-related demographics can be characterised using a simple (time-varying) first order vector autoregressive, VAR(1), process, where population counts at each age depend on just three ingredients:

- Fertility,
- Age- and sex-dependent survival, and
- Net migration.

Using this time-varying VAR(1) process, see the Appendix for notation, it is possible to record the evolution of the entire age structure through time.[6] A VAR representation, when time-variation in demographics has ceased, makes it easy to assess whether the population will converge (and how quickly) to a given steady-state level or whether it will continue to grow or conversely decline.

In our overlapping generations paper, we intend to discuss in more technical detail the circumstances in which the age proportions settle down to steady state values. This is an important consideration for the OLG modelling. In Stats NZ's median projections, which guides our benchmark demographic projection, the total population converges to a steady state level because fertility is less than replacement and the net migration impulse is a fixed number of total migrants. The convergence of the total population to a given level also means that the age proportions eventually converge. The later paper discusses whether the age proportions will eventually converge to this steady state from an arbitrary starting point, even if the population as a whole is growing. The paper shows that migration is very important to facilitate this convergence to steady-state age proportions if the population is growing. With flexibility about net migration, any population growth rate can be achieved and the age proportions can be stabilised, but net

[5] See Binning et al. (2024), forthcoming.

[6] We use the term VAR as shorthand and because it is evocative of the underlying structure of the stochastic process. More formally, one could call this model a matrix inhomogeneous difference equation with time-varying parameters, since net migration does not have the usual stochastic properties of an error term in a VAR model.

migration must be finely balanced to stabilise the age profile (which may be difficult to manage in practice). In the absence of carefully specified migration, the age proportions can cycle perpetually, depending on initial conditions.

National population projections

Stats NZ, via its Aotearoa Data Explorer tool,[7] provides forward-looking national population projections, complementing historical population estimates and population counts associated with national censuses. The projections are estimates of New Zealand's future population size, composition and distribution, based on assumed fertility rates, survival probabilities, and rates of net migration. The current projections extend forward from a base year of 2022 through to the year 2073 (although Stats NZ has provided the Treasury with additional data that projects forward through to the year 2100). Stats NZ's projections are stochastic – i.e., they incorporate randomness into the underlying assumptions – to highlight the wide array of population outcomes that could arise in the future. Stats NZ also provides various scenarios to indicate the types of outcomes that might arise if some of the underlying assumptions change – for example, scenarios with very high fertility; very high survival rates; no (net) migration; cyclic migration; and very high migration.

The three components provided by Stats NZ – fertility rates, survival probabilities and net migration – are the building blocks of the demographic inputs for our OLG model. To ensure that the projections methodology we apply does not stray too far from Stats NZ's, we have replicated the projections from Stats NZ to the year 2100. We have found that our projections closely resemble Stats NZ, as seen in Figure 1. It is worth noting that in its published projections Stats NZ aggregates all 95+ year olds into one group, resulting in a spike in the population counts that we have located at age 95, (partially evident in the middle panel of our figure). For the sake of our analysis and the inputs required for the OLG model, we have extended the age profile from Stats NZ to a maximum age of 117 by applying Stats NZ's survival rates for 95+ year olds to the remaining population count of each respective 95+ age, showing the steady decline in population numbers as people grow older.

It can be seen in Figure 1 that our projections closely align with Stats NZ's projections. There are some small differences reflecting differences in underlying assumptions that we have made. In the rest of this section we discuss the assumptions being made about fertility, survival rates, and net migration. Later we combine these three assumptions to see how they interact with each other in shaping New Zealand's demographic profile over the projection horizon.

Fertility

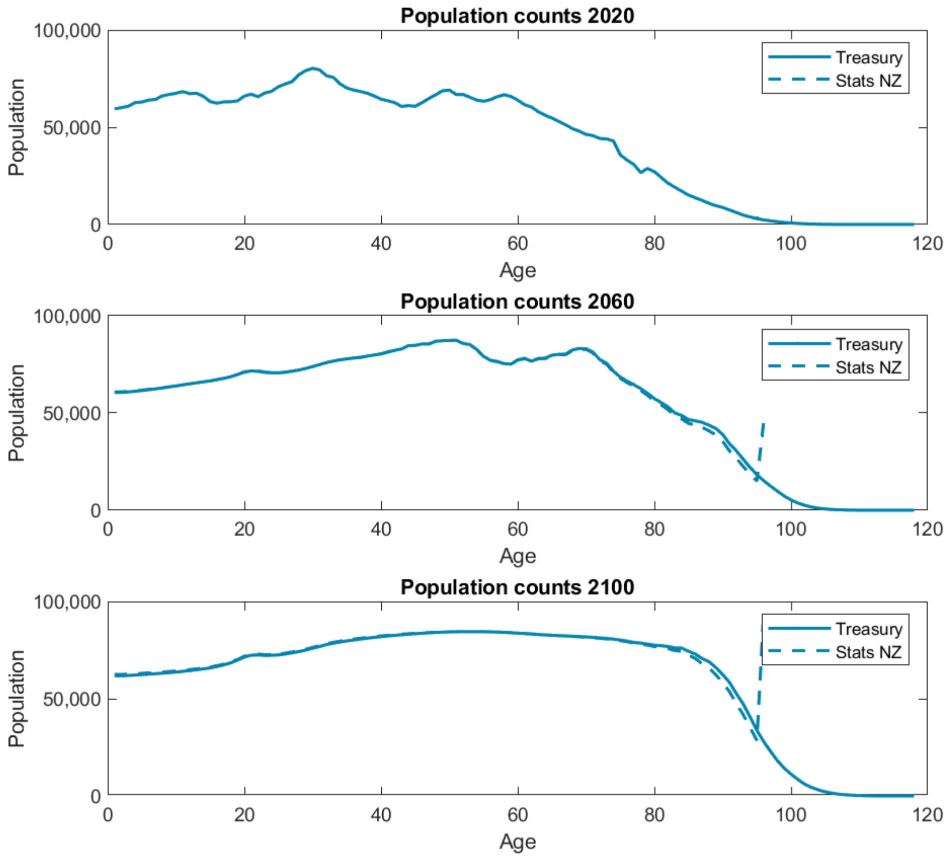
Total fertility rates serve as an indicator of New Zealand's reproductive behaviour, reflecting the average number of children born to women during reproductive years.[8] Fertility rates play a major role in demographic trends, societal dynamics, and economic forecasts more generally. They influence New Zealand's labor force, health care systems, social welfare programmes, and play a pivotal role in the size and composition of New Zealand's population going forward.

Leaving aside migration for a moment and assuming fertility and survival rates are constant, a population will be approximately constant in size if women during their period of fertility produce enough children to replace themselves, their partners and any others who died before they were able to reach fertility. Total fertility rates need to be around 2.1 children per woman to maintain

[7] See https://explore.data.stats.govt.nz/.

[8] The total fertility rate is the sum of age-specific fertility rates from a given year. Total fertility rates are a cross-sectional measure at a given point in time. They are a rough guide to average *longitudinal* lifetime fertility for women.

Figure 1: Population projections, Treasury/Stats NZ comparison



Source: Authors' computations and data obtained from Stats NZ.

population size.[9] Survival beyond the age of fertility affects the shape of the age distribution, but fertility and survival before the age of fertility are the key drivers of whether a population grows or declines in aggregate.

Stats NZ reports historical fertility rates as part of its reporting on births and deaths. As seen in Figure 2, total fertility until the 1980s was either at, or above, the replacement rate (approximately 2.1 babies). From 1980-2010 total fertility rates varied in the region of 1.9-2.1, but since 2013 they have consistently slipped below 2.1; in the last five years total fertility has been below 1.72 live births. In the year ended June 2024, the total fertility rate dropped to just 1.53 births per woman. The median population projection from Stats NZ assumes the total fertility rate varies throughout the projection, but with a median of around 1.65 births per woman from 2036 until 2100. Stats NZ also provide 25th and 75th percentiles from their stochastic projections. The 25th percentiles for total fertility steadily decrease from a rate of 1.54 to a low of 1.33 in 2100, while the 75th percentiles increase, with fertility rates starting at 1.54 and nearly reaching 2 by 2100.[10]

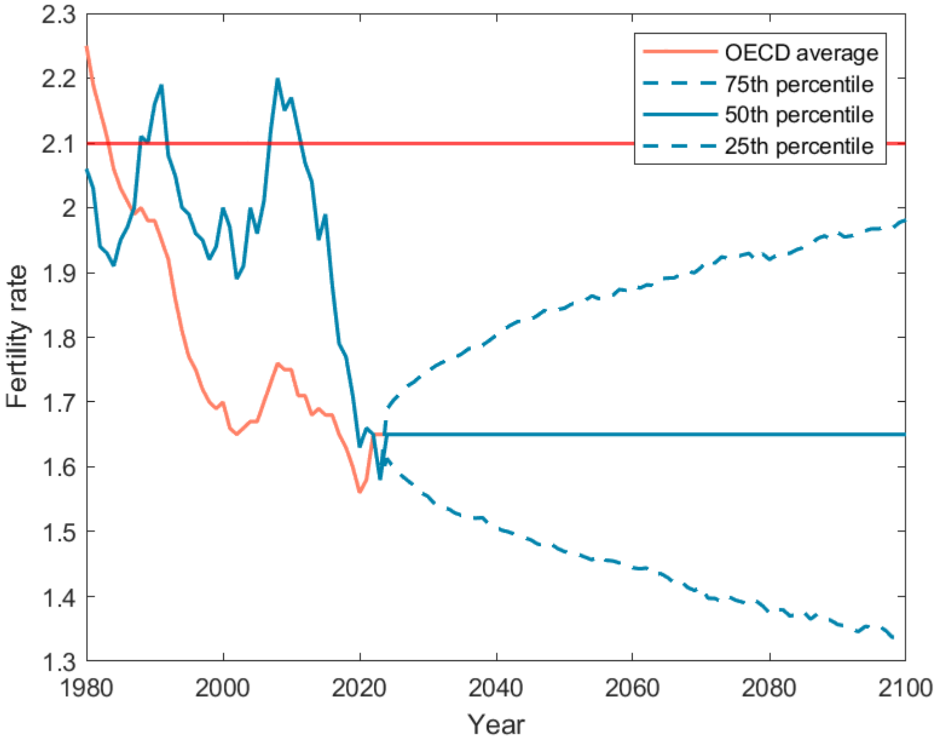
This fertility projection is also broken down by ages 12 to 49, showing that across all projection years, peak fertility is reached in a female's early thirties (with approximately 11% of females giving birth each year at that peak), and drops off on either end in a bell shaped curve to even-

9 The replacement depends on survival rates for women prior to fertility and the sex-ratio of babies, so 2.1 births is an approximation.

10 These percentiles report cross-sectional features of the 2000 simulated population paths.

tually reach 0 at ages 12 and 50. Stats NZ reports fertility only for females (i.e. there are no male fertility rates).

Figure 2: New Zealand's historical fertility rates



Source: Stats NZ.

New Zealand's decline in fertility is mirrored in the outcomes for other high income countries and seems unlikely to change in the near future. According to the United Nations,[11] fertility in high-income countries was on average 1.561 in 2022. The countries with fertility rates above 4 are located in Africa, with the addition of Afghanistan. Countries with lifetime fertility above 3 are generally located in Africa and Oceania, together with a number of others like Kazakhstan, East Timor, Tajikistan, Iraq, Pakistan, Palestine, Iraq, and Comoros. With the exception of the Faroe Islands and Monaco, the UN reports that all developed countries had lifetime fertility rates below 2 in 2022.

The repercussions of falling fertility rates are far-reaching. Demographically, declining fertility rates contribute (in the transition towards steady state) to population ageing,[12] resulting in an inverted age pyramid characterized by a larger elderly population relative to the working-age population, as we will see later in this paper. This poses challenges for health care systems, social welfare programmes, and intergenerational equity. Economically, a shrinking workforce may hinder productivity growth and place financial pressure on pension systems. Moreover, declining fertility raises concerns about fiscal sustainability, since (in the absence of migration) superannuation commitments and any public debt will represent a burden on a smaller group of economically active tax-payers.

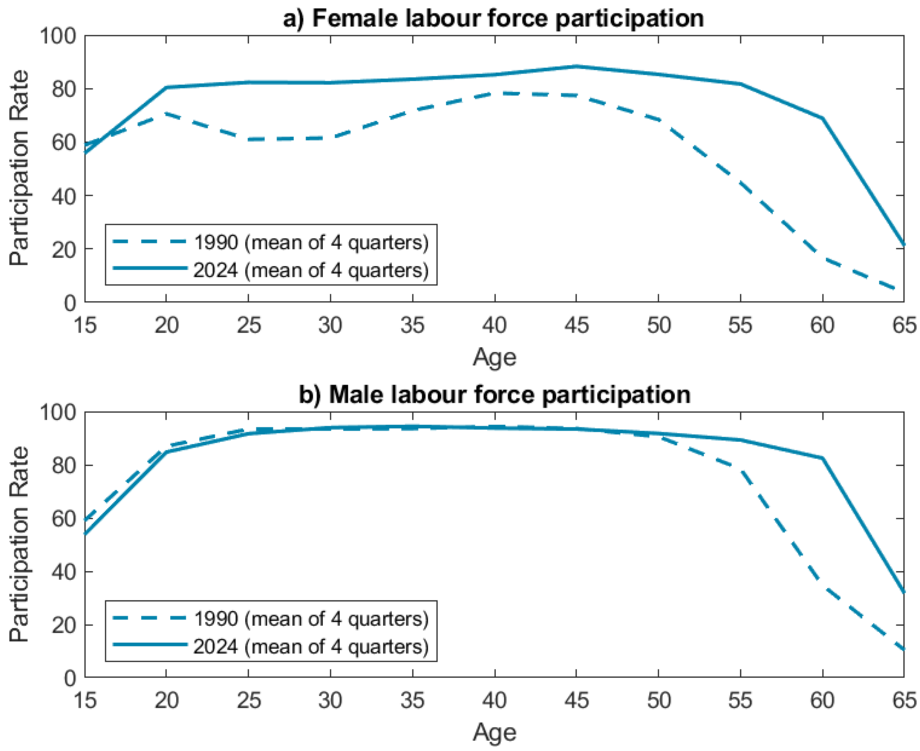
That said, declining fertility rates have coincided with greater labour force participation by women. As seen in Figure 3, female labour force participation has shown a large increase – in 1990, approximately 60% of women worked, whereas by 2024, the labour force participation of women

[11] See https://data.un.org/Data.aspx?d=PopDiv&f=variableID:54.

[12] Noting of course that declining mortality rates are also important in increasing the population share of the elderly.

had increased to approximately 80%. Male labour force participation rates have mostly held constant. Figure 3 also shows the increasing rates of elderly labour force participation: for females aged 60+ in 1990 participation was as low as 20%, increasing to above 60% in 2024. A similar trend is seen for elderly males.

Figure 3: Male and Female Labour Force Participation Rates



Source: Stats NZ.

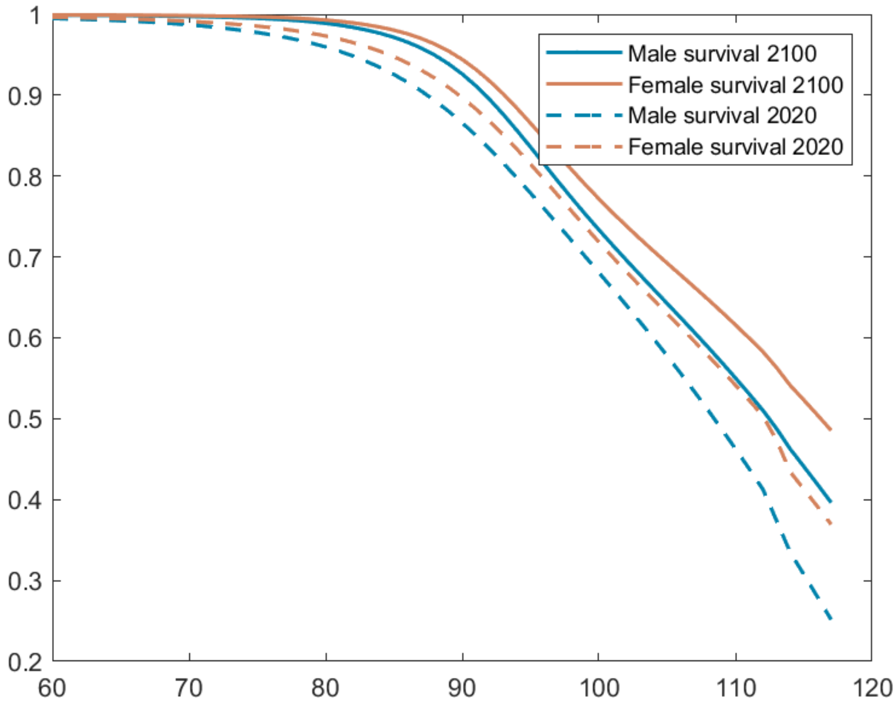
Survival probabilities

Survival probabilities refer to the likelihood of an individual or a population surviving from one period to the next. These probabilities are influenced by various factors such as advances in health care, technology, education, and living standards. We have seen in New Zealand (and much of the developed world) that survival probabilities have been steadily increasing due to decreasing smoking rates, improvements in medical treatments, disease prevention, and in some countries, access to clean water and sanitation. As a result, individuals today have a higher chance of living longer and healthier lives compared to previous generations.

On average, women have consistently outlived their male counterparts across various populations worldwide, a trend that has persisted for decades and is also evident in New Zealand. Figure 4 shows survival rates in New Zealand split by males and females, projected from 2020 to 2100. Survival rates are projected to trend upward for both sexes, but the sex gap in life expectancy is expected to persist, with women projected to outlive males for all projection years.

Increasing survival rates carry significant implications for fiscal expenditure on health care and superannuation, and are also likely to induce changes in labour supply among older individuals.

Figure 4: Male and Female Life Expectancy



Male and female survival rates, 2020 and projections for 2100. Ages 60-117 presented since all ages under 60 have a survival nearly equal to 1. Source: Authors' computations and data from Stats NZ.

Migration

Given New Zealand's falling fertility rates, positive net migration is becoming increasingly important for New Zealand to grow or simply maintain its population size.

Stats NZ has produced a net migration profile for New Zealand by sex and age for 2020, and has migration projections going all the way to 2100. Stats NZ assumes that annual net migration will vary from year to year, but with a median net gain of around 25,000 a year from 2026.

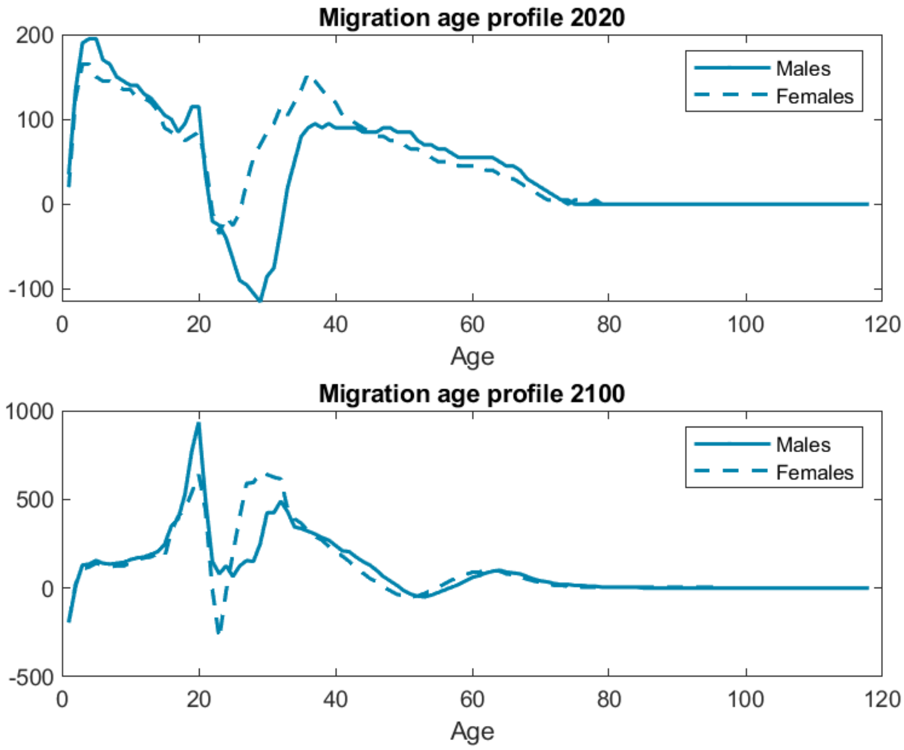
The net migration profile shows some interesting sex and age related trends, as seen in Figure 5. The top panel shows the age profiles by sex for the year 2020, and the bottom contains the age profiles for 2100. The figure illustrates that net migration into New Zealand tends to be positive for people between the ages of 0-20, and 35+, but negative over the 20-35 age range, likely due to a large proportion of young, educated people leaving New Zealand after they finish study. Although there are differences present across sex (for example, a greater number of males than females leave New Zealand in their thirties), the overarching trend is consistent.[13]

Migration is challenging to project given that it is the result of a complex interplay of various factors including relative economic opportunities, government policies, political stability, social dynamics and environmental conditions.[14] Each of these factors can evolve through time. Shifts in policies, sudden economic changes, conflicts and natural disasters can all quickly change migration trends, making forecasts inherently uncertain. In addition, individual decisions influenced by personal circumstances further contribute to the unpredictability of net migration. As

[13] It is worth noting that the age-sex profile does vary according to the overall net migration level, it is not a constant distribution across age-sex.

[14] Weinstein and Pillai (2001, p. 223) suggest that migration is the most complex process studied by demographers and that it is one of the most difficult to measure and explain.

Figure 5: New Zealand's Net Migration, 2020 and projected to 2100



Source: Stats NZ.

can be seen in Figure 6, migration since the year 2000 has been very volatile, and an assumption of a median net gain of around 25,000 migrants per year does not capture the volatility of these past net migration flows. Reflecting this uncertainty, Stats NZ considers a number of different scenarios as previously mentioned. The 'no migration' projection abstracts from net migration altogether; the cylical migration projection assumes that a net +25,000 migrants arrive a year in New Zealand on average, but with flows ranging from -5,000 to +60,000 a year and the very high migration scenario considers a case where annual net migration is +50,000 a year from 2023 onwards.

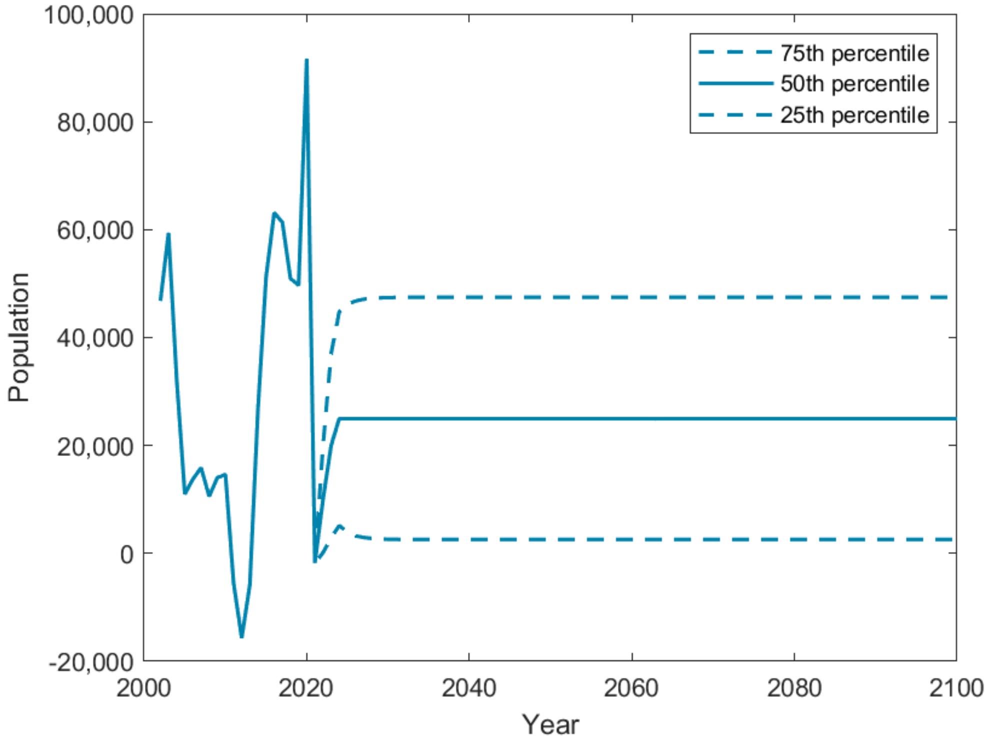
Cohort shares in steady state

In the presence of migration, and assuming the steady state values for fertility and survival rates discussed in previous subsections, the population counts in the year 2100 present several structural differences relative to the population in 2020.

Figure 7 shows that there is a much larger proportion of older people in the population in 2100 than in 2020, and a corresponding decrease in the proportion of younger people. The share of 0-62 year olds is consistently larger in 2020 than in 2100, and the opposite holds for those aged 63 and older. The share of 85 years olds in the population is projected to increase from under 3% in the year 2020 to over 10% in the year 2100. Figure 7 identifies population shares as the population size in 2100 is projected to be more than 2 million people larger than in 2020.

There is a sex difference evident in the population projections. Year on year, more male babies are born than female (using the ratio from 2023, 51.64% of babies are male and 48.36% are female). This means that for every 100 females born, there are approximately 105 males, leading to a larger proportion of young males in the population. However, males face lower survival rates than females. In the year 2020, this has meant that by the age of approximately

Figure 6: New Zealand's Historical Net Migration



Source: Stats NZ. The dotted lines represent the 75th and 25th percentile projections. Authors' computations based on the median projection.

30, the sex split in the population is equal. Then as that cohort continues to age, and males continue to face lower survival rates, the sex proportion shifts in favour of women. In the year 2020, female life expectancy is projected to exceed that of males by about 3.5 years.

The difference in life expectancy is projected to continue. As can be seen in Figure 8, given the increasing survival rates projected by Stats NZ, both males and females are living longer. Improving male survival rates mean that by the year 2060, the share of males will exceed females until the age of 60. Beyond age 60, lower male survival probabilities tilt the population shares in favour of females. A continuation of this trend means that the sex split equalises at the age of 80 in 2100.

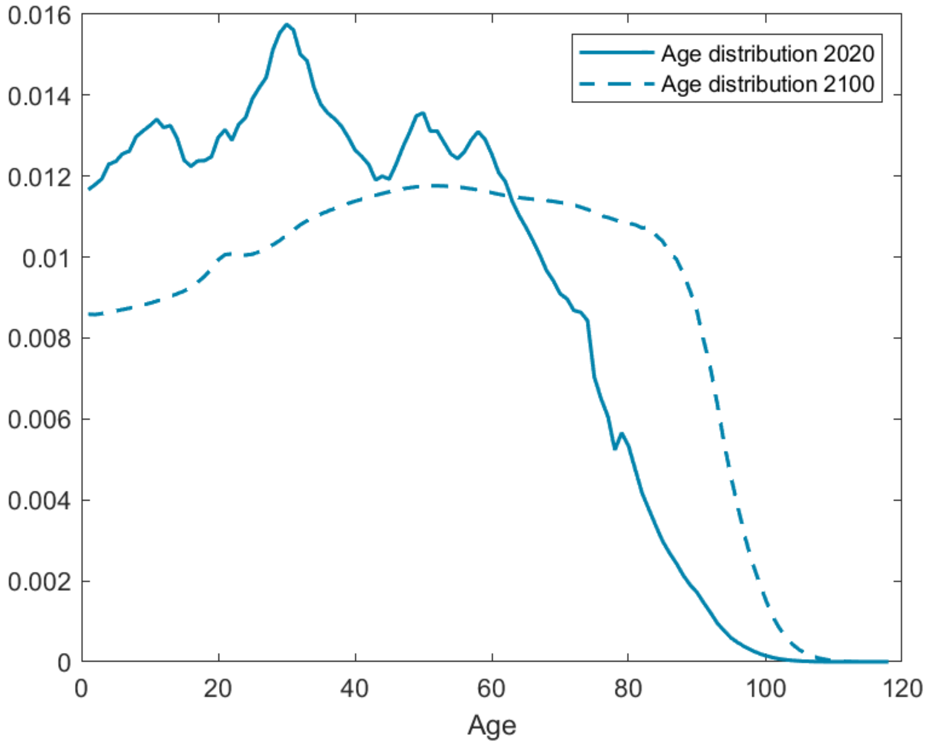
Long-term projections

As previously mentioned, the projections that we have from Stats NZ end in the year 2100. Since our OLG model studies how the age structure evolves to its eventual steady state, it relies on population projections that go out significantly further than 2100.

To extend the projection, we have taken the transition matrix containing fertility and surivival probabilities and the migration vector from the last year (2100), and assumed that they are representative of fertility, survival and migration rates for all years after 2100. (See the Appendix for a description of the transition matrix.) As per Figure 9, our model shows that the population converges at just over 7.5 million people by around 2500, with most of that population growth occurring by the end of this century.

As mentioned in the migration subsection, New Zealand is increasingly relying on migration to maintain its population. With the fertility rates in our projection, the number of babies born

Figure 7: Age profiles, 2020 vs 2100



Source: Authors' projections based on Stats NZ median projections.

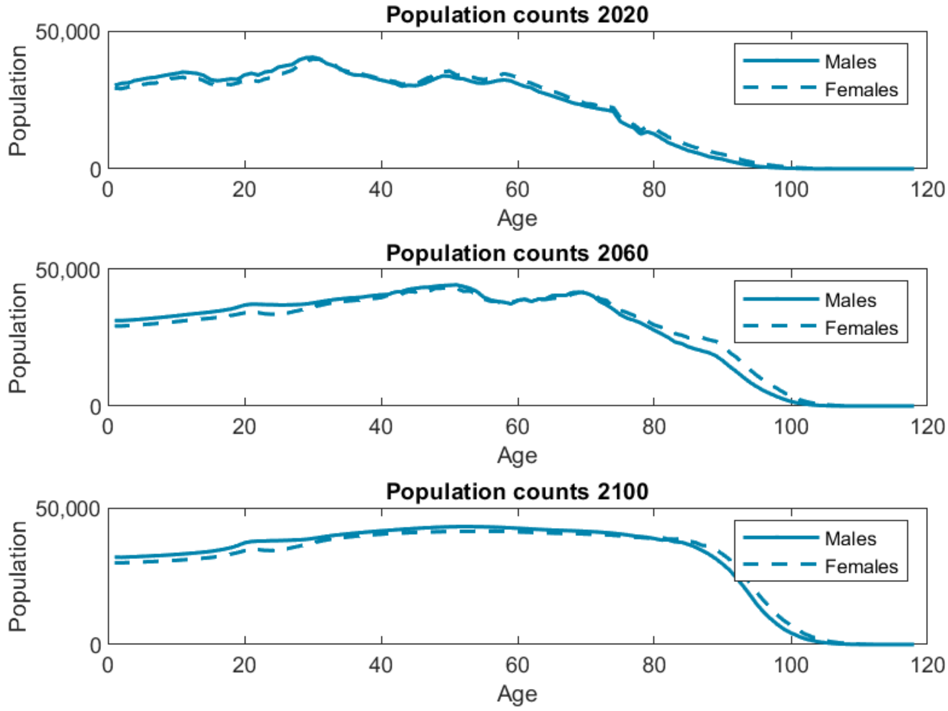
each year ranges from 59,440 in 2020 to 64,145 in 2100. This does not lead to enough babies to sustain New Zealand's population and, as seen in Figure 9, if not for the 25,000 migrants entering New Zealand year on year New Zealand's population would be on a steady decline. These projections should not be taken too literally. However, they do illustrate the importance of considering fertility, mortality and net migration as drivers of long-run population demographics.

When fertility rates fall below the replacement level, as has occurred in New Zealand, migration becomes a key factor in sustaining population levels (and/or population growth). With New Zealand's birth rate declining, there is a natural decrease in the working-age population and, at least in the transition, an increase in the proportion of older individuals, leading to economic challenges such as changing labor participation and pressure on social welfare systems. Unless migration flows are increasingly dramatic and growing, they cannot offset the changing age demographics associated with improving survival rates.

Implications for superannuation

Demographics should play a significant role in shaping superannuation policy, as they directly impact factors such as workforce participation rates, life expectancy, and retirement savings behaviour. As populations age and life expectancy increases, there is a growing need to ensure that retirement savings are sufficient to support individuals throughout their extended retirement years. Additionally, demographic shifts, such as changes in the ratio of working-age individuals to retirees, can affect the sustainability of pension systems and the adequacy of retirement incomes. Variations in individuals' characteristics, such as income levels, education, and employment patterns, and policy interventions, including tax rates and the design of superannuation, can influence how and when individuals save for their own retirement. Therefore, understanding the population shares of different agents is important to design effective superannuation

Figure 8: Age profiles, 2020, 2060 and 2100



Source: Authors' projections based on Stats NZ median projections.

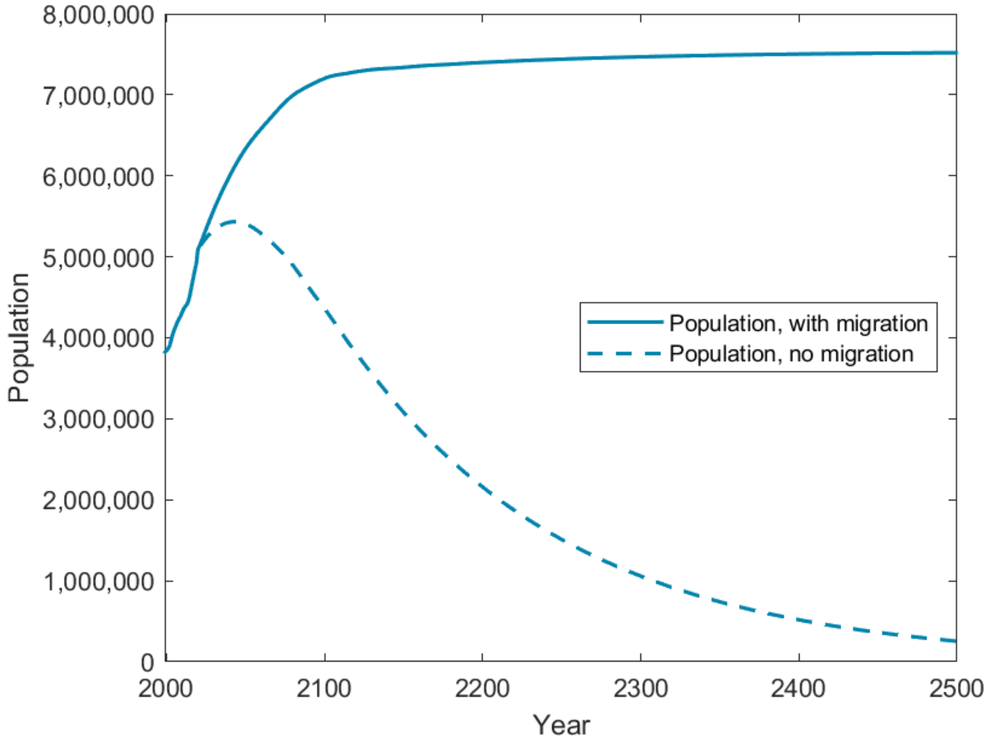
policies that support financial security in retirement.

A demographic indicator commonly used to understand this phenomenon is the 65+ dependency ratio. This is defined as the number of 65+ year olds per one hundred 15-64 year olds in New Zealand's population. The 65+ dependency ratio has increased gradually from 14 in the mid 1960s, to 25 in 2022, and according to the projections is expected to reach 57 in 2100. The proportion of people over the age of 65 is expected to double by the end of the century, representing this large shift in the make-up of New Zealand's population. Plot a) of Figure 10 provides a visual representation of how the different age groups in New Zealand is set to evolve from 2020 until 2200. The shares of young and working age people in the population remain relatively steady. The age group that is increasing most is those over 60. See Figure 10. Note that 'working age' in Figure 10 is represented by 21-65 year olds, which is the pre-retirement age in our OLG model, though there is nothing that prevents older individuals from continuing to participate in labour markets after the age of 65. These demographic pressures need to be considered alongside the increased labour force participation and productivities of older age cohorts.

Figure 11 provides an alternative perspective on population ageing by illustrating what age would stabilise the dependency ratio through the projection at levels equivalent to the current 65+ dependency ratio. By the end of this century, this age increases to approximately 80. This dependency-stabilising age should also be considered in conjunction with labour participation of older aged workers. While labour force participation has increased in older cohorts, it does not reach the levels seen in prime working-age individuals, as we saw in Figure 3.

Transfers to superannuitants are paid for out of general government revenue. Under current superannuation policy settings, the revenue directed towards superannuation as a share of gross domestic product (GDP) is projected to increase 50% by 2061 according to Treasury's

Figure 9: Population projections



Source: Authors' projections.

2021 Combined Statement on the Long-term Fiscal Position and Long-term Insights Briefing (*He Tirohanga Mokopuna)*,[15] increasing further thereafter if median demographic projections are correct. Government revenues are not magicked from thin air, but are obtained through taxes and charges for publicly-provided services. If superannuation transfers increase because of demographic ageing then the government must either increase revenue (through taxation or other charges) or decrease expenditure on other services.[16] Alternatively, the government could change superannuation policy settings, to reduce the associated fiscal cost of transfers to superannuitants. The reasons for supporting the elderly are not being questioned here. Rather, the ultimate aim is to understand how those decisions affect the fiscal position of the government and to consider what policies might best achieve the desired objectives.

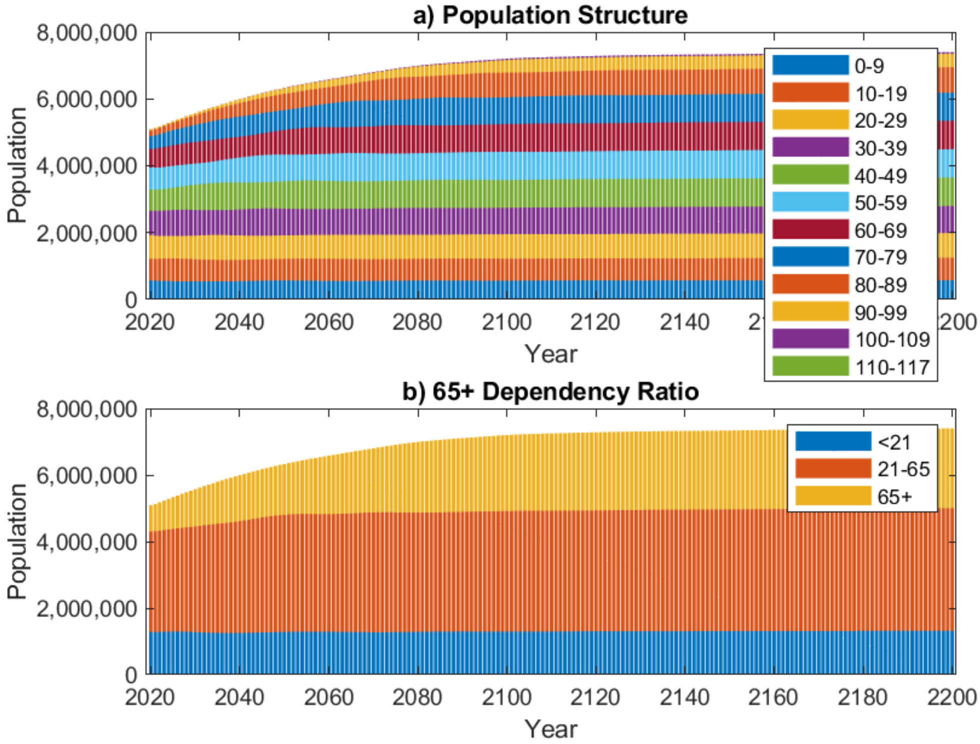
The New Zealand Superannuation Fund was instituted in 2002 with the intention of accumulating assets that could be drawn on to assist with funding superannuation as the New Zealand population ages. While this fund provides some assistance, Treasury analysis illustrates that it addresses less than a quarter of the increase in net-of-tax superannuation as a percentage of GDP (see pages 55-57 of *He Tirohanga Mokopuna*). Occasionally, it is also suggested that productivity growth may provide relief from these demographic pressures. However, superannuation is indexed to wages (or inflation) and thus productivity growth also serves to increase superannuation payments. Under current policy settings, there is no easy way to 'grow' our way out of these fiscal pressures.

Demographic changes, such as an ageing population, develop gradually and can be anticipated well in advance through changes in birth rates, life expectancy, and migration patterns (recognising however that migration is very unpredictable). Despite the clear signs pointing towards

[15] See https://www.treasury.govt.nz/publications/ltfp/he-tirohanga-mokopuna-2021.

[16] The 'real' impact of any decline in expenditure may be moderated if the government becomes more efficient in delivering services.

Figure 10: Population structure



Source: Authors' projections based on Stats NZ median projections.

these shifts, it may be tempting to delay taking action when the full impact might not be felt for decades. However, addressing these demographic challenges should begin well in advance because any policy changes affect lifetime savings decisions and capital accumulation, which cannot be adjusted instantaneously. People saving for retirement need advanced notice of any change in policies so that they can adjust their lifetime consumption and savings behaviour.

Sensitivity of projections to varying assumptions

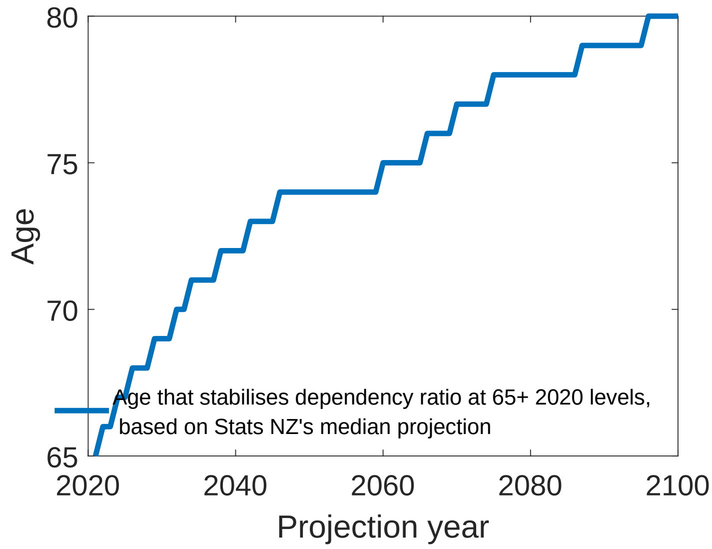
In this section, we vary the individual components of the model to evaluate the impact that these changes have on the demographic projections, focusing on how total population numbers change in each scenario over the coming 500 years. By adjusting the parameters within specified ranges, we look at the influence each of these has on the model's projections.

We illustrate different fertility rates using 25th and 75th percentile estimates from Stats NZ. Figure 12 shows that the aggregate population falls to around 4.4 million using the 25th percentile, but continues to grow exponentially in the 75th percentile scenario.

We also depict a flat reduction of 2% on the survival probabilities for every age over every year of the projection horizon. This reduces the total size of the population to 1.6 million by the year 2350.

We have already noted the extent to which New Zealand's population projections depend on migration. As seen in Figure 12, if net migration is reduced to zero, New Zealand's population steadily declines to zero by 2500. If net migration is increased to 1% of New Zealand's population (which is larger than the fixed value assumption of 25,000 migrants as per the median case), then it grows exponentially, as seen by the top dashed line in the figure. Some slightly more subtle cases are seen when we assume that long-run net migration is 2,500 or 47,500

Figure 11: Dependency-stabilising age



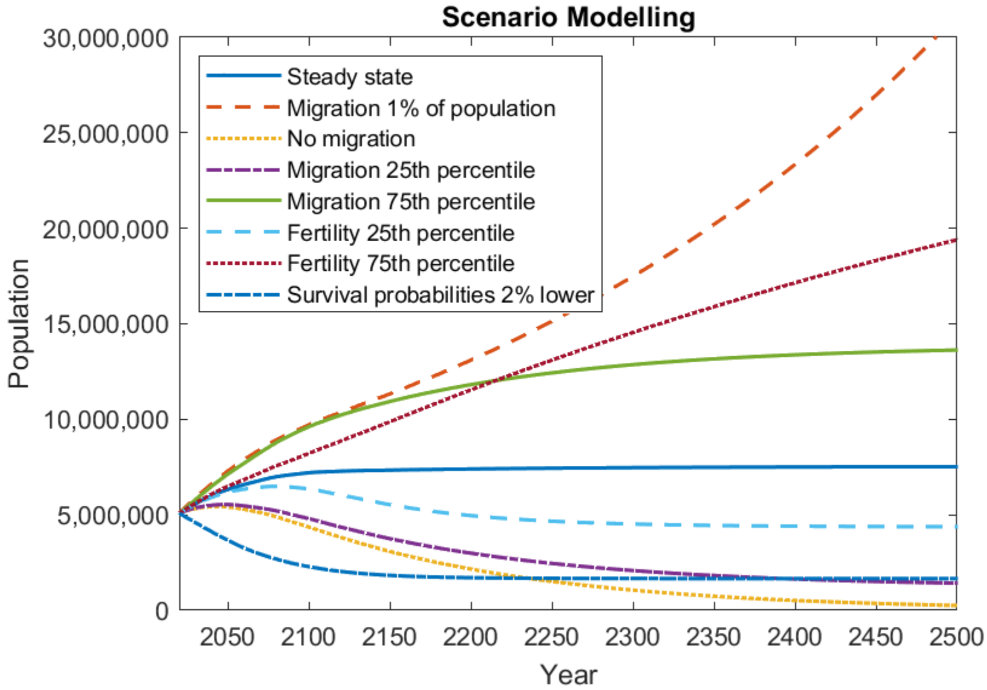
Source: Authors' projections based on Stats NZ median projections.

migrants respectively (corresponding to 25th and 75 percentiles in Stats NZ's net migration projections). The lower migration scenario results in a steady state population size of under 1.5 million, and the higher migration case yields a population of approximately 13.5 million.

The demographic components assessed in this paper, fertility, survival rates and migration rates, are not stable and will also be affected by policy changes. Policy decisions on health care, tax incentives, superannuation, early childhood policies, and many others, will feed in to demographic outcomes. Robust health care systems can improve survival probabilities by reducing mortality rates and enhancing overall life expectancy. Similarly, tax incentives can alleviate financial burdens on families, increasing birth rates. Superannuation policies, which affect retirement savings and financial security, can also impact migration rates, as individuals may move to regions with more favourable retirement benefits. Early childhood policies, including access to education and childcare, can further shape fertility decisions by making it easier for parents to balance work and family life. These interconnected policies create a complex landscape where changes in one area can affect various aspects of people's private decision making.

These scenarios highlight the sensitivity of demographic projections to each of the individual inputs. A modification which may not seem particularly large, when accumulated over decades or centuries, can have a significant effects on long-run population dynamics. This highlights the need for critically evaluating all assumptions that feed into demographic projections and, in our case, to consider the impact that each of these scenarios has on the OLG model.

Figure 12: Scenario Modelling



Source: Authors' projections.

Conclusion

Understanding the implications of population growth and demographic shifts has been an important focus in economics since Malthus's 1798 *Essay on the Principle of Population*. This paper presents an overview of the main insights we have gained from our demographic analysis for the OLG model. It shows many of the trends seen in New Zealand's recent history, such as New Zealand's fertility rates declining below replacement rate, increasing survival probabilities, ageing population, and migration impulses. The baseline projection implies that New Zealand's population will reach approximately 7.5 million, though this outcome depends crucially on net migration rates given the historically low fertility rates that have been experienced over the last seven or so years. If there was zero net migration, then New Zealand's population would decline to zero. These projections should not be interpreted too literally. Fertility and migration are endogenous choices driven by expected benefits and costs,[17] which evolve with the policy environment and the size and composition of the population. However, they illustrate some of the possible outcomes that should be considered when policy frameworks are designed.

The Treasury is currently developing an Overlapping Generations (OLG) model to understand how demographics affect consumption and savings behaviour, capital accumulation, the long-term costs of superannuation policy and their fiscal policy implications more broadly. Unless there is a massive change in longevity (or in fertility and net migration), New Zealand's population will age substantially. The projected increase in the 65+ dependency ratio (relative to working age population), from 14 in the mid 1960s to 57 in 2100, highlights the challenge that lies ahead for fiscal policy. This paper is not questioning the rationale for supporting elderly in need, but it does illustrate the pressures involved from providing such support, and emphasises the challenges that come with navigating demographic transitions to ensure the long-term economic sustainability and prosperity of New Zealand.

[17] Todaro (1980) describes the Todaro model in which the expected benefits of urban-rural migration drive choices to migrate.

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Appendix

The representation of demographic dynamics

Let N_{t-1} be a column vector, corresponding to the age counts of males stacked above the age counts of females in the population. To economise on notation, we depict ages from $0, 1, 2, \ldots, 10$, which might be thought of as decades; our actual analysis keeps track of population counts for each year of age for both males and females.[18] Define,

$$N_{t-1} = \begin{bmatrix} N_{t-1}^{m,0} & N_{t-1}^{m,1} & \ldots & N_{t-1}^{m,10} & N_{t-1}^{f,0} & N_{t-1}^{f,1} & \ldots & N_{t-1}^{f,10} \end{bmatrix}' \tag{1}$$

This vector denotes the number of people alive at time $t-1$, where an m denotes males, and an f denotes females. Generically, $N_{t-1}^{m,s}$ is the number of males of age s alive at time $t-1$ and $N_{t-1}^{f,s}$ is the number of females of age s alive at time $t-1$. Define a transition matrix T_{t-1} that shows how the vector of people alive transforms into the number of people alive at time period t, N_t, reflecting both survival rates and fertility. Assume also, that the population is augmented with a vector of (net) migration, with its own age structure:

$$M_{t-1} = \begin{bmatrix} M_{t-1}^{m,0} & M_{t-1}^{m,1} & \ldots & M_{t-1}^{m,10} & M_{t-1}^{f,0} & M_{t-1}^{f,1} & \ldots & M_{t-1}^{f,10} \end{bmatrix}' \tag{2}$$

where again M_{t-1} is a column vector. $M_{t-1}^{m,s}$ in this vector reports the net number of males of s years of age who entered the country at time $t-1$ (immigrants less emigrants), with $M_{t-1}^{f,s}$ an analogous count of females. N_{t-1} can be thought of as a 'stock' of people at the end of the period and M_{t-1} is the 'flow' of migrants. If $M_{t-1}^{\cdot,s}$ is positive (with $\cdot \in \{m, f\}$) more people migrate to New Zealand with those sex and age characteristics than leave New Zealand. Note that the dating of our net migration impulse is consistent with the representation of demographics in d'Andria et al. (2020), but slightly different to traditional cohort-component modelling, as per United Nations (2022), where net migrants dated time t augment the stock of people in time t. We use this dating convention for the flow of net migrants because it is consistent with the convention for capital and debt accumulation in our OLG model, where date t stocks and flows determine date $t+1$ stocks. Keeping the same timing convention simplifies the calculation of per capita variables in the OLG model.

The dynamics of the age counts can then be represented as:

$$N_t = T_{t-1} \times N_{t-1} + M_{t-1} \tag{3}$$

Or expanding this notation:

$$\begin{bmatrix} N_t^{m,0} \\ N_t^{m,1} \\ \vdots \\ N_t^{m,10} \\ N_t^{f,0} \\ N_t^{f,1} \\ \vdots \\ N_t^{f,10} \end{bmatrix} = T_t \times \begin{bmatrix} N_{t-1}^{m,0} \\ N_{t-1}^{m,1} \\ \vdots \\ N_{t-1}^{m,10} \\ N_{t-1}^{f,0} \\ N_{t-1}^{f,1} \\ \vdots \\ N_{t-1}^{f,10} \end{bmatrix} + \begin{bmatrix} M_{t-1}^{m,0} \\ M_{t-1}^{m,1} \\ \vdots \\ M_{t-1}^{m,10} \\ M_{t-1}^{f,0} \\ M_{t-1}^{f,1} \\ \vdots \\ M_{t-1}^{f,10} \end{bmatrix} \tag{4}$$

[18] In its published projections Stats NZ aggregates population counts for ages 95 and above. We have unpublished demographic projections for ages up to 116.

The following array depicts demographic transition matrix T (abstracting from time-variation in that matrix), where again the ages could be interpreted as decades rather than single years. The components to the left of the vertical dotted line and above the horizontal dotted line are simply to facilitate understanding and are not part of T. Fertility has been illustrated as occurring for females in their twenties, thirties, and forties. The (near-diagonal) survival probabilities illustrate that it is not possible to jump directly from, say, age 4 to age 6; to get to age 6 one needs to have been age 5 in the previous period. The matrix is not invertible because of the columns of zeros for individuals in their last year of life (year 10 in the matrix); everyone is assumed to die thereafter.

$$
T = \begin{array}{cc}
 & \text{Age at time } t\text{-}1 \\
 & \begin{array}{cccccccccccccccccccccc} 0&1&2&3&4&5&6&7&8&9&10&0&1&2&3&4&5&6&7&8&9&10 \end{array} \\
\text{Age at time } t \;
\begin{array}{c} 0\\1\\2\\3\\4\\5\\6\\7\\8\\9\\10\\0\\1\\2\\3\\4\\5\\6\\7\\8\\9\\10 \end{array}
&
\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&\omega_m f^{m,2}&\omega_m f^{m,3}&\omega_m f^{m,4}&0&0&0&0&0&0 \\
p^{m,1}&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&p^{m,2}&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&p^{m,3}&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&p^{m,4}&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&p^{m,5}&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&p^{m,6}&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&p^{m,7}&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&p^{m,8}&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&p^{m,9}&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&p^{m,10}&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&\omega_f f^{m,2}&\omega_f f^{m,3}&\omega_f f^{m,4}&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&p^{f,1}&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&p^{f,2}&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&p^{f,3}&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&p^{f,4}&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&p^{f,5}&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&p^{f,6}&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&p^{f,7}&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&p^{f,8}&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&p^{f,9}&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&p^{f,10}&0
\end{bmatrix}
\end{array}
$$

Ignoring the time subscripts for the moment, the first row of the matrix T shows how many male babies are born to females of fertile age, where fertility is assumed to take place in a woman's twenties, thirties and forties (in our actual analysis from age 12 to age 49 years of age). We assume that the sex of newborns is independent of the age of mothers, so that fertility rates and sex proportions can be multiplied directly to find the probability that a mother of age s has a female (or male) baby. Again ignoring the time dimension to conserve notation, f^s represents the proportion of females of age s giving birth, and ω_m represents the proportion of those babies that are male.

The 12th row of the matrix, corresponding to age zero for females (remembering that male ages run from 0 to 10) likewise characterises the relationship between female births and fertile-age females, with ω_m replaced by ω_f, which is the probability that a birth results in a female (i.e., $\omega_f = 1 - \omega_m$).[19] For simplicity, we assume the male and female baby proportions are fixed at 0.5164 and 0.4836 percent respectively, consistent with December 2023 live male and female births as reported by Stats NZ.[20] The zeros before the non-zero entries in in the 1st and the 12th rows correspond to: (i) males who do not give birth and (ii) younger-age females who do not give birth; the zeros after the fertile-age observations reflect (iii) ages where female fertility is zero.

[19] The analysis here is an approximation for the purposes of macroeconomic analysis, and so we do not break the distribution down further, e.g., by ethnicity, by region, or by other identifiers.

[20] See https://infoshare.stats.govt.nz/. The proportion of females born annually, from 1971 to 2023, has varied between a minimum of 48.1% to a maximum of 49.2%.

Most of the remaining rows in the matrix relate to survival rates, and illustrate the proportion of people of age s at time $t-1$ that survive to be age $s+1$ at time t. E.g., each row is a vector of zeros, *except* it has a non-zero value between 0 and 1, corresponding to the probability that a male of age s, say, at time $t-1$ survives to be a male of age $s+1$ at time t and similarly for females.