An investigation of regional infant mortality trends in New Zealand, 1873-1940

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Abstract

From as early as the middle of the nineteenth century until the 1930's[1], New Zealand's infant mortality was one of the lowest in the World. The unique background conditions of New Zealand determined some of the initial advantage in the survivorship of infants in the first year of life relative to other European countries. This advantage then persisted into the twentieth century. The nature and causes of epidemiological transition and mortality decline (in general) in New Zealand have been extensively analyzed in the demographic literature ((e.g. Pool, I., Cheung, P., (2003), Pool, I., Cheung, J., Amey, B., (2009)). In this paper, however, we examine the effects of socio-economic *and* demographic variables on infant mortality decline, by testing (using unobserved components models for univariate time-series, and SEM for pooled time-series) some of the hypotheses put forward in the literature using new time series data (1873-1940) from the four main provincial districts. Essentially, the results recognize the differential importance of socio-economic factors on infant mortality in light of demographic transition in New Zealand. This paper contributes to a much broader understanding of the underlying mechanisms of infant mortality decline in New Zealand during the late 19th – mid 20th centuries.

Acknowledgements

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[1] Gibson, A. C. (1973)

I. Introduction

New Zealand during the early 20th century has been considered one of the healthiest nations in the world. By the time the first life-tables were constructed in the 1870s, non-Maori (mainly Pakeha for much of the period covered in this paper) had achieved significantly higher levels of life-expectation at birth than levels recorded from the British Isles' populations from where they were drawn - even the English[2]. New Zealand, as many other European countries, saw a decrease in mortality around the time of the rapid economic development that came with the refrigeration era and an increased urbanization. The most rapid improvements occurred at younger ages, which were also among the earliest in the developed world. European infant mortality exhibited some variations in the timing of decline and the course of change in infant mortality during the nineteenth century. Woods R. and others (1989) identified three distinct patterns of this decline across Europe: Swedish, French and British. Unlike England or Germany, where infant mortality began to drop only towards the end of the century, Sweden was probably the first country that displayed a pattern of early and fairly steady decline throughout the nineteenth century. Apart from Iceland, other Nordic countries (e.g. Denmark, Norway, and Finland) experienced a similar decline. We could also relate Austrian decline in infant mortality occurring in 1870's to a "Swedish" pattern. The French pattern, followed by Belgium and possibly Italy, was found to exhibit a later decline – dated from 1890, with a temporary reverse in the late 1890's. The last pattern describes Great Britain where infant mortality rose between the 1880's and 1890's, and only started declining from 1899, which is often identified as a turning point. New Zealand could be distantly related to a Swedish pattern, because of their similarities in population densities with large proportions living in rural areas and a household-based food production. New Zealand infant mortality rates, however were much lower those in Sweden, where infant mortality seldom reached levels under 100 infant deaths per 1000 live births prior to 1900.

Historic and demographic literature presents us with diverse explanations of the nature of infant mortality decline in European countries, and a comprehensive analysis is likely to suggest multiple factors and multiple reinforcements. Woods R. I and others (1989) emphasized the following factors responsible for initiating the decline in England and Wales: the decline in fertility (both marital and illegitimate), long-term improvements in levels of women's education, improved "health of towns" (e.g. availability of fresh water), and the improvements in milk supply and food quality, the availability of more highly qualified midwives, institution of ante-natal care and a post-natal health visitor service.

The causes for the infant mortality decline in Sweden remain unclear. Past studies interpreted the results in different ways, with the emphasis being put on: the interrelationship between infant mortality and the general nutritional status of the population (e.g. wheat consumption or wages); the expansion of general health services; changes in the social

[2] Pool, I., Boddington B., Cheung, J., and others (2009). "Differential trends in the compression of mortality: Assessing the antecedents to current gaps in health expectancy in New Zealand," p. 31.

structure of the population; and the quality of infants' diets[3]. The studies that argued the monocausal explanations of trends in infant mortality have been proven unsatisfactory: infant mortality is clearly conditioned by a combination of social cultural, biological, economic and attitudinal factors[4].

In France, the decline of young infants in 1900 resulted from the diffusion of the scientific advances of the era, especially the pasteurization of milk. In fact, from the mid-1880's, there was a multiplication of public and private interventions promoting better infant-feeding practices.[5] The main causes of infant deaths in cities till 1930's were diarrhoeal diseases, which tended to exacerbate during hot summer months. During the interwar period, the slow rate of decline in infant mortality was generally attributed to cultural factors (a high fertility and strong religious practices) or to unfavourable socio-economic conditions.

Previous demographic studies extensively analyzed the nature and causes of epidemiological transition and mortality decline in New Zealand (e.g. Pool, I., Cheung, P., (2003), (2005); Pool, I., Cheung, J., Amey, B., (2009)). Pool, Cheung (2005) analyzed life expectancy in New Zealand and the reasons as to why non-Maori life expectation was so high so early. They point out several explanations such as exclusion of Maori deaths, advantageous economic conditions, surplus of meat proteins in the diet, low population densities in cities and temperate climate. They pay special attention to fertility decline (fertility decline mainly induced by changes in nuptiality) as the most important factor that had a direct effect on individual's health. Although, New Zealand mainly consisted of migrants from British Isles, the Pakeha family of the late 19th century deviated markedly from its British counterpart. Pool I. (2007) explains that marriage patterns were very different, fertility levels were higher and nuclear families were more likely to be neolocal.

In general, New Zealand's economic, social and disease environment was rather different from anywhere else in the world. As noted earlier, New Zealand followed a Swedish pattern but unlike Sweden did not experience a setback in 1900, with infant rates being much lower in New Zealand on average. There were no major pandemics throughout the nineteenth century that would claim many lives in New Zealand (e.g. cholera, smallpox – vaccination introduced early). There were no sharp regional differences present as recorded in many European countries (e.g. Sweden, France). Urbanization statistics from the four major centres identifies that urban proportion was even falling during 1870's and 1880's till 1890. Despite an increasing proportion of population moving to the cities, with the opening of various manufacturing industries, the population density was not nearly as high as in US or Britain. And even in cities there were no tenement slums, people generally owned their own homes and most had an access to garden plot, vegetables and fruits in central urban areas[6]. Primary education was made free and compulsory in 1877, which was also considered to be high quality for that time period. New Zealand's unique environment created advantages of comparatively low infant rates from the start, therefore the subsequent decline was not as dramatic as in other developed countries.

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[3] Brandstrom, A., published by UniCef (1993)
[4] Same
[5] Rolle, C., Bourdeiais, published by UniCef (1993), pp. 432-442
[6] Pool (2007)

The secular decline in infant mortality from the beginning of the 19th century (around 1900) seems to be a universal phenomenon. This epidemiological and health transition has very close ties with economic development, industrialization and the change in technology. The timing for the decline varied because of the country-specific economic, social and disease environment. The New Zealand pattern of infant mortality decline would be initially different due to its unique geographic, economic and social background conditions; however, the underlying processes of its subsequent decline would still be similar to those in other countries. We believe that the determinants of infant mortality in New Zealand are more complex than identified in the existing demographic literature, and the urbanization and economic processes set the initial conditions and are the underlying drivers of its decline or increase at the macro level.

Pool I., Cheung J. identify that "...the mortality history of Pakeha New Zealand in the late 19th and early 20th centuries could be seen simply as documenting another exception to epidemiological transition (Casselli, Mesle and Vallin 2002), or it could raise more fundamental theoretical questions." They proposed a set of general hypotheses (some of them were rejected in the process) with regards to overall mortality decline, however, some explanations relate to infant mortality as well. According to their analysis, changes in biomedical and public health did not play any significant role on the decline. And only after the Public Health Act (1900) was introduced, the basic public health and medical infrastructures and regulations were formed. The set of co-varying factors was presented: fertility decline affected by changes in patterns of nuptiality (direct effect), by high level of economic development and by the reinforcement of economic change by the policy environment and structures put in place at the end of the 19th century (indirect effects). They recognize a twofold effect between fertility and infant mortality (through decrease in acute infective causes and accidents and through the decrease of the physiological burden of childbearing leading to a decline of rates of females at reproductive ages). Due to lack of readily available data, these hypothesized relationships were realized through "pointing to associations with trends in various factors co-varying over time with mortality changes." To model and directly test some of the hypotheses put forward in the literature, we collected and generated a set of new socio-economic variables (e.g. real wages, public health expenditure per capita etc.) for the four major provincial districts (Auckland, Canterbury, Otago, Wellington) for the period 1873-1940. Time series data and methods allow us to take the quantitative approach and to examine the effects of these socio-economic and demographic variables on infant mortality decline, data on different provinces brings a spatial aspect to this analysis. Some of the advantages of our data are listed below:

- New (constructed from the Official Statistics) real wage, public health, infant mortality and education data for the four main provinces allows us to estimate the effects of socio-economic variables, given the structural framework specified in the literature, in a model rather than just by using covariates.
- Time series data captures yearly fluctuations, reducing the degree of error when smoothing over long periods.
- Data for the four major provinces allows for the South versus North comparisons

With so much emphasis on the fertility decline through nuptiality changes as the main mechanism of the infant mortality decline. We would like to empirically test the validity of the proposed in theory relationships, with slightly shifting the emphasis to more remote determinants of fertility and infant mortality: the underlying economic and social conditions. Pool I., Tiong J., discussed some of the socio-economic determinants of fertility. With the regional economic data available, more quantitative analysis is to be undertaken.

The paper can be divided into two parts: analytical and empirical. In the analytical part, we would like to revisit and further discuss the hypothetical relationship between fertility and nuptiality and infant mortality. In the *Analysis and Discussion* part we introduce aggregate analysis of infant mortality in New Zealand in relation to other countries during 19th-early 20th centuries, then discuss the anticipated effects of real wages, real per capital public works and health expenditure, education, and marriage patterns, presenting the provincial level data. The *Methods and Modelling* part begins with analysis of time-series persistence (various unit root tests). Individual province analysis employs time-series methods with unobserved components using Kalman filter (STAMP software)[7]. Lastly, given endogeneity of some of the explanatory variables and their complicated interactions, we build a SEM within the panel data setting to observe the effects of demographic and socio-economic variables. The final section summarizes the results and draws conclusions.

II. Analysis and discussion

i. Existing Framework and hypotheses

Infant mortality is defined as a micro level phenomenon with macro level implications. It can be inferred from the literature that biomedical and nutritional status of mother and child have a direct immediate impact on infant mortality, which are influenced by micro social factors such as income, marital and fertility patterns, access to water supply, urban/rural residence within macro social environment (e.g. political, economic, social system). It is often hard to disentangle the effects of socioeconomic variables on health in general and infant health in particular. For instance, nutrition variable is categorized as "medical," and impacts on health via biosocial and biomedical mechanisms.

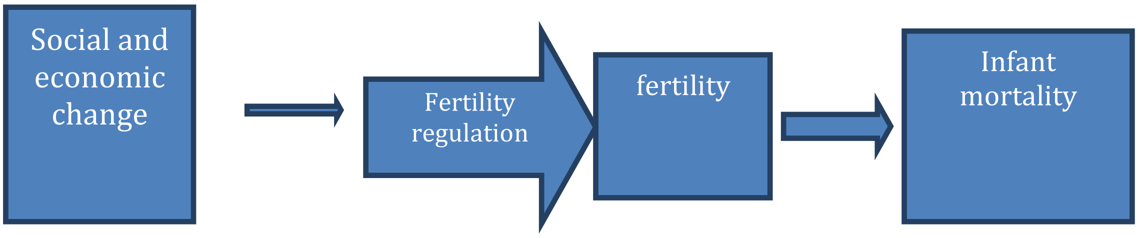
In this paper, we focus on the macro effects, by testing an existing in the demographic literature mechanism of infant mortality decline in New Zealand (we draw the concept from the work of Ian Pool).

The approximate framework of the infant mortality decline in the nineteenth century New Zealand proposes fertility as the major causal factor for the infant mortality decline. The proximate determinants of fertility decline are the changes in patterns of nuptiality (fertility regulation mechanism)[8]. The set of determinants for such mechanism are represented by social and economic change variables such as real wages, female education, expenditure on public works and health, levels of urbanization or degree of technological change.

[7] "STAMP (**S**tructural **T**ime Series **A**nalyser, **M**odeller and **P**redictor) is a statistical / econometric software system for time series models with unobserved components such as trend, seasonal, cycle and irregular". - http://stamp-software.com/

[8] An analytical framework to Study Fertility change was described in Pool, I., Tiong, F., (1991), p.50

Figure 1. Schematic framework of the causal links of infant mortality decline



Pool recognized nuptiality as a means of controlling reproduction. Specifically, according to his analysis, there was a shift in conjugal patterns from universal and early marriage in 1870's to delayed entry into unions and spinsterhood for a significant majority of women by the 1900's (Sceats and Pool 1985). By 1901, Pakeha women had adopted the British pattern of late marriage and significant levels of spinsterhood. The same pattern was adopted in other European countries. From the mid-1880's the population of the Nordic countries adhered to the West-European marriage pattern, age at first marriage being high and many remaining unmarried, which limited family size. The marital fertility, however, was high, and combined with high illegitimacy rates from the eighteenth century on, resulted in comparatively high crude fertility[9]. This was not the case in New Zealand, with fertility dropping below the replacement level in 1900's. Sceats and Pool 1985, demonstrated that almost two-thirds of the fertility transition came from the shift in patterns of nuptiality, and that the most rapid changes occurred prior to 1900, which were again different in other European countries where improvements were radical only after 1900. Post 1870's decline was characterized by relatively constant levels of nuptiality and fertility, while infant mortality continued to decline even after 1900. Improvements in cities' infrastructure, introduction of various public health acts and initiatives in the post 1900 period could definitely play a role here.

The "change in values" implies changes in socio-cultural preferences, with women becoming more independent and more educated. With the beginning of refrigeration and before mechanization of milking, milkmaids were in high demand. Since, preferences were given to single women, delaying marriage and kids seemed reasonable for women wanting to undertake those sorts of occupations (e.g. milkmaids, housemaids)

Clearly, this "change in values" was driven by more intensive economic growth and urbanization. Urbanization and relative economic environment in each region provided incentives for the shift to smaller families. The earlier defined mechanism proposes that the better care for infants (shift from older children to parents caring for infants) came with the subsequent decline in infant mortality occurred because of the reduction of the family size. Accord to Pool I. (2007), the typical "preventive check" mechanism was operating in New Zealand in the early 1870's, since the use of known contraception in fertility regulation during 1878-1901 was limited (Pool, 2007).

[9] Edvinsson, S., and others, (2008), p. 462

With the reduction of family size, women were more likely to look after their infants themselves, since the infectious diseases and accidents were found to be the main causes (see Pool 2007). Pool claims that the latter occurred because parents had older children to look after the newborns while at work. The official statistics identifies the most common diseases in 1872-1876 among infant to be diarrheal, then “other causes” that could potentially be attributed to accidents. In other countries, the breastfeeding practices were extremely important for the infant care and reductions in mortality (e.g. in Norway, Sweden and France). Not much is known about breastfeeding practices in the nineteenth century New Zealand, however, if we assume that parents would transfer the care for infants to other children, then it would mean that many of those infant were not regularly breast-fed or that they were fed-artificially (cow milk). This could be another reason for the higher infant mortality and its reduction due to reduction in diarrheal diseases that became even more apparent with the Plunket nurses’ activities.

Based on this framework and results from existing literature, a set of arguments and testable hypotheses had been put forward:

1. Fertility regulation via nuptiality change as a means of controlling reproduction was the main driver of infant mortality decline in late 1870’s. Pool, I., Tiong, F., (1991) provided this analytical framework of fertility change. They attempted to capture sub-provincial differences only by analyzing rural and urban provincial GFRs. By adding socio-economic data to this analysis, we would like to model the framework they provided and test the mechanism empirically.

2. From the work of Pool I., and Tiong, F., some differences in fertility patterns are present across regions (due to a different economic base of the rural regions). We would also like to detect any persistent dissimilarities or common/similar features across provinces, and whether those were comparable with variations in fertility rates.

3. European demographic literature distinguishes quite complex relationships between infant mortality and its determinants, we as well deliberate that social and economic variables are not strictly operating through fertility-nuptiality mechanism, but rather exhibit a combination of direct and indirect forces that drives infant mortality to decline.

4. The most radical improvements in infant health occurred in European countries after 1900, while in New Zealand those changes are described to happen much earlier. Despite that, infant mortality in New Zealand was also affected by improved infrastructure, various public health acts and initiations in 1900s. Infant mortality continued to decline in 1900s, while nuptiality and fertility remained relatively constant after 1900, implying that the nature of infant mortality decline in 1870’s would be different from the 1900’s.

5. Urbanization and relative economic environment in each region would have provided incentives for the shift to smaller families. Urbanization would also have a simultaneous effect on both infant mortality and fertility decline.

6. As the free compulsory schooling introduced in 1877 changed values relating to the enforcement of school attendance which served as a function of society's shifting attitudes to child labour, as evidenced in the Factories Act 1894,[10] we believe that female education is one of the most important determinants of fertility and infant mortality.

7. The role of public health and medical science, which were regulated through improved infrastructure, in the last quarter of the nineteenth century, was crucially undermined in the literature. Even in the early years Government has made some attempts to organize a system of public health and made vaccination compulsory for all infants (Public Health Act of 1872), but especially big improvements occurred in the 1900's, starting with the foundation of the department of health, immediately followed by Public Health Act of 1900, the 1903-1904 Midwives Registration Act, the 1909 Hospitals and Charitable Institutions Act, and continuing with the activities of Plunket nurses, in particular, directed to improve infant care and mother's health.

8. Assuming the preventive check was operating in the nineteenth century New Zealand, and even later in the twentieth century with fertility being regulated within marriage through contraceptives etc. (Pool I., 2007), then there exists a direct positive association between wages and fertility.

Some of the issues, discussed above, have historical underpinnings and cannot be directly tested, other are subject to direct testing and modelling. We discuss some parts of these issues and assumptions in greater detail in the analytical section, leaving the rest to be empirically tested in *Methods and Modelling* part of this paper.

ii. Infant mortality decline in retrospective

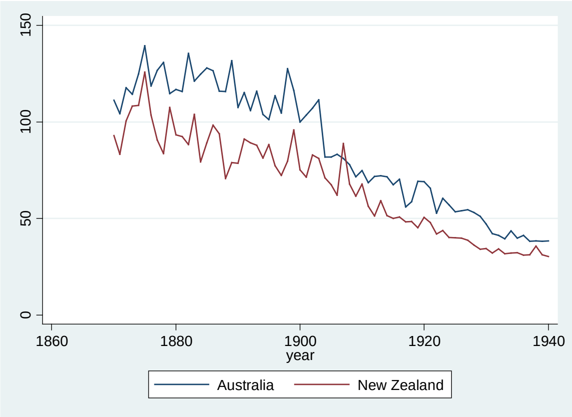
Earlier, we identified some of the most common causes of infant mortality decline in other European countries. There was no definitive answer, in general though, empirical evidence supports the idea that improvements in economic conditions in the 19th century were fundamental in the decline in death rates in the developed world. This said, the economic environment in New Zealand could be considered as "unique" both in terms of its demographic and epidemiological transitions. Infant mortality data reports that the decline occurred in the mid-1870s, which was at least two decades earlier than in Australia or Britain. As an example, Figure 1 represents the gap between New Zealand and Australian infant mortality rates, which is persistent throughtout the 1876-1940 period.

[10] Pool, Tiong

The national series identify a significant increase in infant mortality in the mid-1870's, followed by a subsequent decrease. Largely, only in the mid 1870s were the infant rates above 100 infant deaths per 1000 live births. In fact, according to McLean (1964), the highest recorded infant mortality was in 1875 (about 125 deaths per 1,000 live births), which was the year "when the death rates for typhoid fever, bronchitis, broncho-pnemonia, and diarrhoea and enteritis all reached record heights, and many of the deaths were due to one or other of these diseases." If we were not to consider this increase in 1870s, the decline seems more gradual, with another era of rapid decline in the begining of 1900's being more pronounced (argument #4). Pool I. (2002) himself mentions the complications of interpreting changes in life expectation or other indices from trends over a few decades, as they did by only looking at general trends with no yearly fluctuations considered. We return to this point later.

Back to our Australia versus New Zealand example, we can only speculate on the relative attributions of different macro-social factors responsible for this differential such as environment, social services, economic development etc.

Figure 2. Infant mortality rates per 1,000 live births



We know that in this particular case, it is not standards of living (wages). If we conside standards of living, Australian aggregate real wages seem to prevail during the period 1885-1908, hence the mortality gap seems to be related to factors other than simple economic.

Figure 3. Aggregate wage indices: New Zealand vs. Australia

Not only New Zealand infant rates were lower than in Australia, life expectancy in New Zealand was also consistently higher. Infant mortality superseded the decline in the overall mortality, largely contributing to an increase in life-expectancy. Pool, I. and Cheung, J. (2002) noted that "..rapid mortality decline at infancy and chlidhood in the late 19th century appear to have been followed by changes at older ages…" increasing life expectancy. The aggregate data confirms that New Zealand's life expectancy was consistently higher for both males and females than in both Australia and the UK.[11]

a) *Regional infant mortality rates*

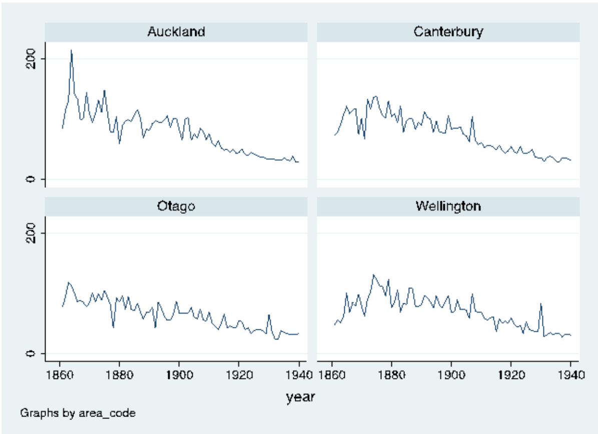
While aggregate dynamics of infant mortality rates is more or less recognized, disaggregate analysis by major provincial district is mostly undiscovered (apart from the work of Pool, I. and Tiong, F. (1991) on sub-national difference of Pakeha fertility decline during 1876-1901). Prior to analysis of the determinants of infant mortality, we would like to introduce the infant mortality rates for each of the four major provinces.

Most data came from the Statistics New Zealand Yearly reports/publications, the New Zealand Census, and the Appendices to the Journals of the House of Representatives. The infant mortality data was collected for all nine provincial districts, but in this paper we concentrate on the four major ones (Auckland, Canterbury, Otago and Wellington). We take the most common definition of infant mortality: all children that died under 1 years of age. Figure 3 represents the infant mortality rates for the four provincial districts. We recognize 1864 peak to be only present in Auckland (the peak reached 214 infant deaths per 1000 live births), with the second highest peak occurring in 1875 during measles epidemic (147 infants died per 1000 live births). It is possible that small pox epidemic was introduced there before the compulsory vaccination had any effects (introduced in 1863), which could also be a response to heightened rates. Since this outlier was not present anywhere else, not much else can be inferred, only that New Zealand regions were quite isolated, especially Auckland region (was not connected to other provinces by land till the railway was built in 1906). Therefore, even if the epidemics happened there it would not spread rapidly on population living in other parts of New Zealand. The common increase in 1874-1875 had to do with

[11] See Appendix 1.

measles epidemic. Measles epidemic was likely to affect neonatal mortality since maternal measles is generally associated with an increased risk of premature labour, miscarriage, and low-birth-weight infants. Irregular hikes prior to that may reflect the effects of other “epidemics” occurring at various times which could have a composite effect on infant mortality during early years: in 1872 - smallpox outbreaks in Auckland and Wellington followed by whooping cough epidemic in 1873 and typhoid in 1874. The fluctuations seem to diminish post 1900, especially evident in Auckland and Canterbury. Wellington and Otago both have a slight increase in the number of deaths in 1930, the reasons for which are unclear.

Figure 4. Infant mortality rates per 1,000 live births, 1862-1940



By carefully examining the four different plots, the 1870’s decline is most evident in Auckland, which seems gradual and more evolutionary rather than revolutionary drop as in some European countries. The increases in early 1860’s and 1870’s are due to migration and more diseases being introduced into New Zealand, however, those were not nearly as detrimental as some infectious disease epidemics of the European scale.

After 1900 the infant mortality rates continued its rapid fall with the improvements in environmental sanitation. The Department of public health was set up in 1901, the main activities of which were directed towards improving sanitary conditions, with a special attention provided to reducing the incidence of tuberculosis and the acute infectious diseases. There were no direct measures undertaken to control maternal or infant mortality because the infant rates were already comparatively low. The direct measures were only undertaken by the Department in 1923. Before that the Royal New Zealand Society for the Health of Women and Children was responsible for the infant mortality problem. This organization established its position with the general public and with successive governments since 1907.

By 1900 the three leading causes of infant deaths were the diarrhoeal diseases, prematurity, and the respiratory diseases, with the former two accounting for nearly half the total deaths.[12] According to the New Zealand Medical Journal (1947), during 1901-1905, 41 % of the infant deaths recorded occurred during the first month of life, and 59 % in the subsequent months of the first year, whereas in 1940's, 73.2 % occurred in the former and 26.8% in the latter period. This means that the great improvement in infant mortality during that time period was entirely due to a reduction of deaths occurring after one month. McLean explains that the Plunket Society were mainly responsible for this reduction in infant deaths, by teaching mothers the methods of infant feeding and nurture laid down by Truby King. The Registration of Births and Deaths Act of 1908 claimed to have made Plunket Society services available to practically every mother in the Dominion before the baby is two weeks old (argument #7).

The official statistics on cause-specific diseases identifies diarrhoeal diseases as the major cause of deaths among infants (about 24% in 1872-76); other causes account for about 16.5 %. The reliability of these data was argued by other authors[13]. The numbers may be underreported or over reported, however, those were consistent over the years. The number of deaths from cause-specific diseases was not large; however, the number of infants that died each year was not large either. We know that deaths from diarrheal and infectious diseases constituted a large proportion of infant deaths in Sweden, England, France and other European countries. For instance, in France the main causes of infant deaths in cities till 1930's were diarrhoeal diseases, which tended to exacerbate during hot summer months. In fact, from the mid-1880's, there was a multiplication of public and private interventions promoting better infant-feeding practices.[14] In the next subsection, we continue to discuss alternative causes of infant mortality decline proposed in the literature.

b) *Fertility, infant mortality mechanisms*

Historically, the relationship between fertility and infant mortality is often found unclear. In the literature, it is usually supposed that a decline in infant mortality stimulates the control of marital fertility. The functioning of this mechanism represents a critical part of demographic transition theory in which mortality decline precedes fertility.[15] The empirical evidence does not seem to support this causal relationship. For instance, Larsson (1988) found no clear connection between levels of fertility and infant mortality. Francine van de Walle's survey (1986) of European data did not reveal the historical evidence that confirms that the decline in infant mortality led to the decline of fertility. Woods, R., and others (1989) presented the figure on the changing balance of fertility and mortality in Sweden, France, England and Wales between 1801 and 1981, which demonstrated dual effects of mortality and fertility in changing contribution of infant mortality to the total number of deaths.

If the link is reversed (infant mortality is the dependent variable), the chronology of demographic change in the late nineteenth and early twentieth century Europe appears more

[12] McLean, (1964), p.178.

[13] Donovan, J. W., (1969)

[14] Rollet, 1990, pp 432-442.

[15] Wood, Watterson 1989 (part2) 122

straightforward. However, several other factors complicate this relationship such as breastfeeding (affects both infant mortality and fertility), the replacement effect (which may operate when fertility is controlled). Even in the early Malthusian framework, wages or incomes were affecting both infant mortality and fertility. Brass and Kabir (1979) also attempted to link these variables by examining the associating between child mortality (0-5) and fertility on nine English regions plus Wales. They found that economic and social development was the driving force that influenced the virtually simultaneous movement of both variables (argument #3). Other results for England and Wales suggest that, once the effects of epidemic diarrhoea are removed, the decline in fertility beginning in the 1870's would have had a positive influence on the succeeding downward trend of infant mortality.[16]

New Zealand's fertility levels, similarly to North America, Australia, and to some Nordic countries, were very high in the 1870's. The European fertility transition also coincided with the timing of infant mortality decline. The decline of both marital and illegitimate fertility from the 1870's served to reduce the level of infant mortality by affecting both the number of pregnancies a woman experienced, and by increasing intervals between successive births. Woods R. etc. (1988) point out that there exists a fundamental difference between an increase in overall fertility induced by changes in nuptiality (a higher proportion of spinsters married during the late eighteenth century) and a decline in fertility determined largely by the control of reproduction within marriage as happened during the late nineteenth century. The latter clearly was not the case for New Zealand. Sceats and Pool (1985a) provided empirical evidence that the initial decline in fertility during the late nineteenth century was the result of marriage postponement. Their results demonstrated the effects of delayed marriage in reducing fertility at younger ages of the female population, they also provided evidence that showed the profile of marital fertility at 20-24 years did not deviate radically from the natural fertility model (i.e. the fertility levels where no form of fertility control is used), indicating limited or no effect of use of contraception in fertility regulation during 1878-1901.

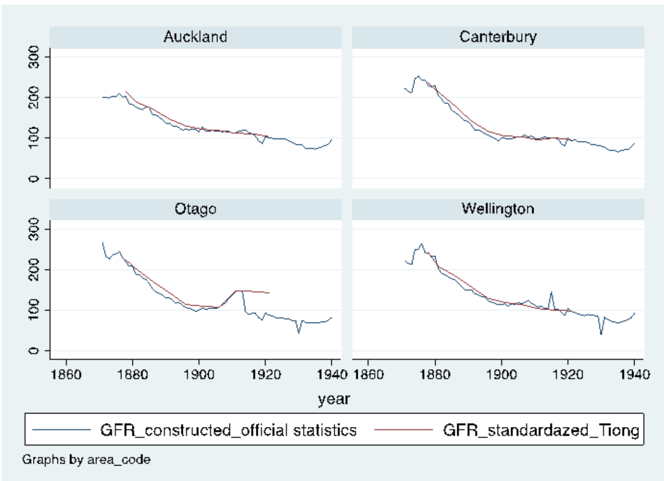
In short, the same causes were driving the fall in infant mortality in the late nineteenth century's New Zealand as in the late eighteenth century's England and Wales. This finding reflects the unique nature of New Zealand economic and social environment. Pool (2007) claims that this Malthusian "preventive check" had existed as a mechanism for fertility regulation even after barrier methods of contraception and other techniques of fertility regulation became more prevalent, also asserting that the effect of public health and mass campaigns only contributed to better health after 1930's. This statement is highly speculative since with an increase in technological progress along the process of industrialization especially evident with the beginning of refrigeration era, both fertility and mortality were declining with population growth beginning to slow down in 1890's as well, which are the characteristics of post-Malthusian period. However, it is possible that till the last quarter of the nineteenth century, fertility was regulated through Malthusian channels, meaning that higher incomes were driving higher fertility and lower infant mortality levels (argument #8). With regards to infant mortality and fertility relationship, we are unclear about the causality of this relationship. The overall mortality results as well show to be inconclusive: Pool,

[16] Hope E. W, (1917), Burns C.M (1942), Reves, R., (1985) in Woods, R. I., Watterson, P. A., Woodward, J.H., (1989), "The causes of Rapid Infant Mortality Decline in England and Wales, 1861-1921 Part 2."

Cheung (2002) in their Pakeha case study found that mortality in New Zealand followed a different from some developed countries sequence of mortality-fertility relationship: “the gaining of relatively low levels of mortality was followed by a rapid fertility decline, but it, in turn, seems to have effected further rapid mortality declines.”

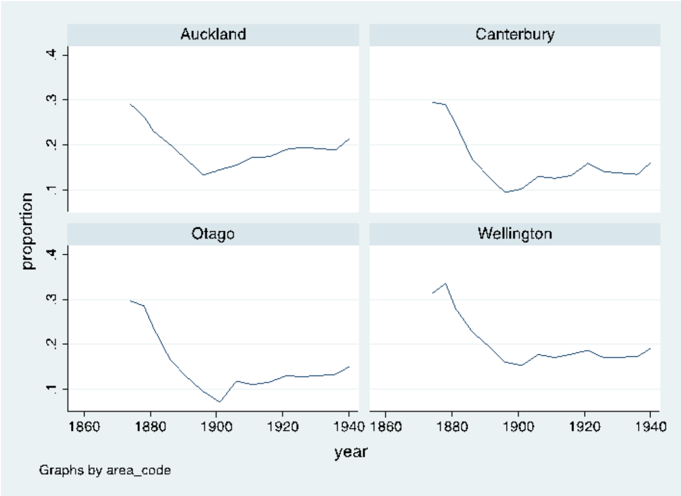
The earlier described mechanism of the effects of fertility on infant mortality through the nuptiality changes is discussed here in more detail. Fertility and infant mortality can be both considered as outcomes of various socio-economic and socio-cultural conditions. Pool and Tiong (1991), in their paper on sub-national fertility trends, presented an analytical framework of fertility change mechanism, that identified (from an analysis based on a form of standardisation) almost two-thirds of the transition came from the shifts in patterns of nuptiality, with the underlying rational of this mechanism being a change in the values of women and couples (hypothesis #1). Social and economic changes were identified as more remote factors that influenced the decision-making process to have fewer children. In particular, they concluded that “cultural determinants...appear to have been superseded by social and socio-economic differences”. The paper did not present empirical evidence on the effects of socio-economic variables, the analysis was purely analytical, utilizing only provincial and regional data on fertility change. The GFR (general fertility rates) were constructed using indirect estimation (conventional indirect standardisation was employed to eliminate age-specific components). In the graph below, we present two series of GFRs (estimated by Tiong and our yearly estimates of the number of births over number of women of child-bearing age):

Figure 5. GFR estimates comparison



It is clear that if we were to smooth our series, we would get almost exactly the same estimates of GFR as estimated by Tiong. The timing of the fertility decline seems to be quite homogeneous across provinces, with Auckland’s GFRs experiencing a more gradual decline compared to other provinces. Since fertility change mechanism (1876-1901) specifies change in marriage pattern as a direct cause, we also plotted the standardized ratios of the number of married women ages 16-24 for the same time period.

Figure 6. Proportion of married women ages 16-24



The series clearly identify relatively smooth trends (the number of women had been interpolated in between censuses), with the lowest percentage (on average) in Canterbury and Otago. We can observe a steady decline in the proportion of married women ages 16-24 in 1870's, which also coincided with the decline in fertility. Clearly, the decline in the proportion of married was much steeper and seemed to reach its low in 1900, after the proportions fluctuated around 20% across provinces. Post 1914, the age of marriage dropped and few married women worked outside their homes, as we may observe the series slightly increase in 1900's, however, the rate of increase seems relatively small. Since fertility is regulated through nuptiality changes, this would have a direct impact on fertility. Not much else can be said about the nuptiality-fertility interactions until a further empirical analysis is done.

Assuming, fertility led to an infant mortality decline in the 1870's, we still believe its contribution to a further decline significantly diminished. We may observe that in 1900's the fertility seems fairly static, nevertheless the infant mortality decline progresses at a much higher rates of decline. Even if the medical care was "non-existent" in the early years (although some attempts were made such as Public Health Act of 1872 that aimed to organize a system of public health and made vaccination compulsory for all infants), there was certainly an improvement in 1900's, starting with the foundation of the department of health (immediately followed by Public Health Act of 1900, the 1903-1904 Midwives Registration Act, the 1909 Hospitals and Charitable Institutions Act) and continuing with the activities of Plunket nurses, in particular directed to more intensive infant care (argument #4). Particularly, Midwives Registration Act establishes a system of training, examination and registration of midwives, and provides for government-funded maternity hospitals to care for less well-off women.

If we refer back to the framework, the remote determinants of fertility regulation are social and economic determinants (e.g. economic conditions, education, and level of urbanization). Pool, Tiong previously postulated some of the indirect fertility measures that would be responsible for changes in preferences or values of nuptiality decisions. In the next section, we discuss the socio-economic determinants in more detail, by adding empirical data to previous analysis.

iii. Social and economic determinants

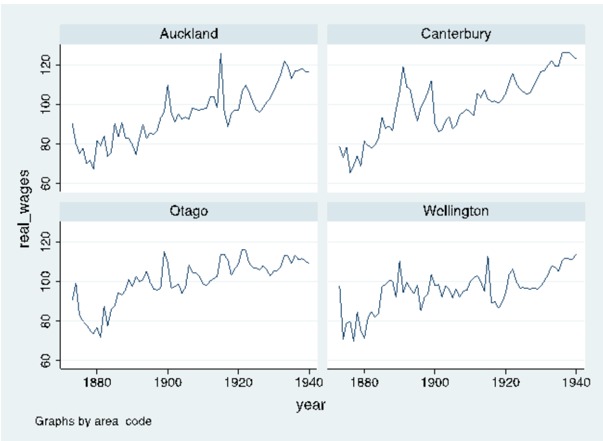
a. Real Wages

As in postulated argument (#3) in section II, we believe that the effects of socio-economic factors on infant mortality are more complex than simply through fertility-nuptiality change mechanism. Generally, it is widely accepted that increasing incomes/economic standards of living on average generate better health outcomes (more disposable income that can be spent on health). Hypothetically, rising living standards should reduce mortality, however, the pattern may be complicated, for example, 18th century Norwegian results did not identify a straightforward and robust correlation between economic resources and infant mortality[17].

It is often that economic data such as real wages is not readily available in a consistent form or does not exist at all during early years of development, however, we were lucky enough that compilation of yearly wage statistics was relatively consistent (since 1873) and we were able to reconstruct real wage series for each of the four major provincial districts using regional deflator series calculated in our previous work. Average real wages measure the economic standards of living in a particular population. The relationship between real wages and demographic variables (whether it is nuptiality, fertility or infant mortality) needs to be examined within New Zealand economic landscape at the time.

The economic conditions have mostly been favourable in New Zealand, especially with the beginning of refrigeration era. New Zealand has always been an exporter of primary products, partly because of that, the "long depression" from the late 1870's to the early 1890's did not seem to strike New Zealand economy as much as was the case in Europe. For example, the English prices, at the beginning of the 1890-1899 decade, declined more rapidly than in New Zealand (given that food comprised a relatively large proportion in New Zealand deflator series, almost 50% of the average working family income would be spent on food (1893 Census)). Provincial data allows us to observe whether there existed considerable differences in real wages across provinces at various stages of economic progress.

Figure 7. Real wage index by major provincial district, 1873-1940



[17] Edvinsson, S., and others, (2008). "Infant mortality in Nordic countries, 1780-1930," p. 471.

Figure 7 reports that provincial differences are most evident in 1890's and 1900's, although the general trend seems to be common across provinces. In fact, the earlier work on regional prices and real wages established (for 1885-1913 period) a high degree of convergence of real wages across four main regions by 1913. The coefficient of variation analysis confirmed that the dispersion among regions had been the greatest in 1890's (the "long depression" seemed to affect provinces differently), which decayed considerably after 1900. Real Wages are expectedly trending upwards from 1880's with frequent yearly fluctuations across provinces. The 1930's depression is also reflected by the dip in all four series.

For more in depth analysis, it is important to discuss the relative position of women in the labour market and the opportunity cost to earning higher wages with more progressive development as that would have a direct effect on decision-making with regards to marriage and family size, which ultimately affect infant mortality.

During 1870's -1920's New Zealand's manufacturing production remained quite local and small scale. The services sector (domestic servants) contributed to about 16 % according to 1911 census. Male-female differentials during 1885-1913 (ratio of real wages of housemaids to smiths and general labourers) remained relatively constant, slightly increasing after 1900's. Post 1890s period also saw an improvement in the ratio between tailoresses and tailors (a reduction of the wage gap between males and females: females' wages being only 50% or less of males' wages in 1885 to 60-65% in 1913). Because of the duality of the labour market with men in the primary sector and women in the secondary, women's sphere of life and work was characterized as highly domestic before the late nineteenth century when certain changes in women's lives and roles seemed to take place.[18] Although, state-instituted arbitration system established in 1894 privileged the male breadwinner, unions were formed with women becoming more active (for instance, tailoresses unions were quite active in Auckland, Christchurch and Dunedin) and the women were granted the right to vote for the first time in 1893. Despite this achievement, government's protective labour legislation between 1891 and 1912 destroyed the late-nineteenth-century push for women's economic dependence, by protecting women through sex-differentiated minimum wages, and restrictions on the hours of work etc., basically channelling women away from good jobs[19]. The state also reinforced women's domesticity through welfare, pensions, maternity benefits and the family allowance. From the 19th century to the 1960s women's role centred on marriage, motherhood, and taking care of husband, home and children. Apart from economic environment, the social conditions and government policies which might have had directly or indirectly determined the underlying reasons for the decisions with regards to marriage and the number of children within the family.

b. Education

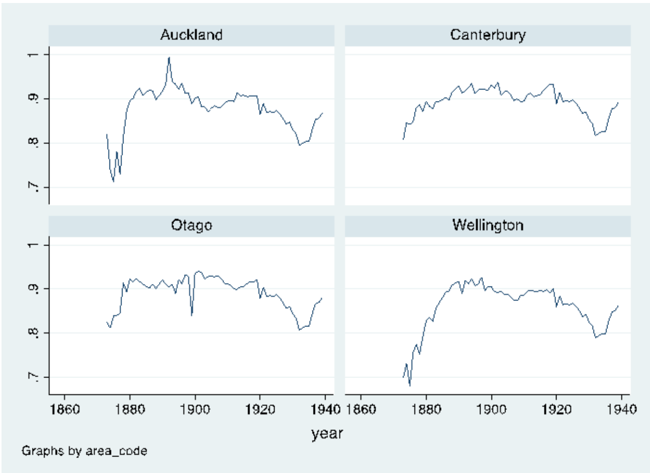
Female education is one variable that has a direct effect on both fertility and marriage rates. Before the abolition of the provinces, each of the provincial governments had made

[18] Nolan, Melanie (1976)
[19] Same, p.27

some sort of provision for primary education in its district, which differed greatly in character and efficiency.[20] Free compulsory primary education was introduced in New Zealand in 1877. Attendance was made compulsory between the ages of 7 and 13. Before 1900 the number of children that received secondary education was not large, especially in rural areas, where there were ony a few local secondary schools[21]. Census data on education was not collected till much later in the 20th century, which was compensated by yearly publications of enrolment statistics in primary and secondary schools. Statistics below represents the female/male enrolment ratio for primary education both private and public till 1919, from 1919 both secondary and primary education were included.

Figure 8 demonstrates a steep increase in the ratio around 1870's. A considerable decline is present in 1930's in all the four series. The first secondary schools originated as Old boys schools, with one feature at New Zealand secondary schools being school Cadet Corps. The ratio was falling during the 1930's economic depression because of the increased number of boys attending boys' schools to be trained for the military purposes and the shortage of teacher's colleges. Besides that, as a general rule girls remained less likely to attend school in the early decades of the 20th century. This was particularly marked at secondary school. From 1944, when secondary school became compulsory to the age of 14, girls' attendance matched that of boys[22].

Figure 8. Female enrolment ratio, 1873-1940



c. Urbanization and Public Works

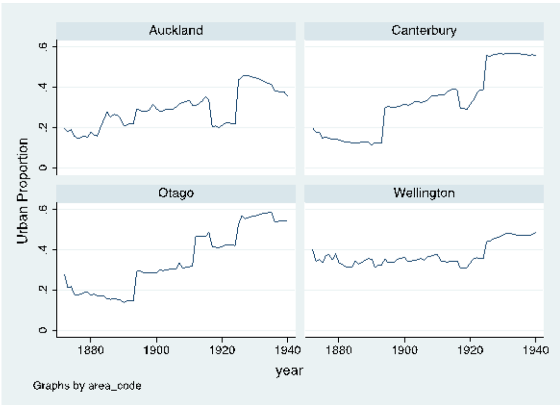
Unlike the more direct socio-economic measures such as real incomes or female education, urbanization and public works set the conditions for all three demographic variables included in the framework (argument #5). Urban environment not only played a crucial role in determining the conditions in which infants were born, but also provided

[20] Irvine, R. F., 1902: "The progress of New Zealand in the Century."
[21] Ash, Graeme. "The School We Magnify" (1991).
[22] Te Ara, Online encyclopaedia of New Zealand

greater opportunities for women, thereby affecting the decision making with regards to marriage and kids.

The "peasant" or "rural-labourer" farming family structure had largely disappeared in New Zealand by the twentieth century[23]. Even by the end of the nineteenth century, despite the image of pastoral democracy and dependence on primary exports, New Zealand was an urbanized society[24]. New Zealand was urbanizing quite rapidly during the period 1860-1940, where the urbanization percentage jumped from 20% to 55-60 %:

Figure 9. Urban proportion, 1862-1940



The cities, however, were not nearly as densely populated as other developed countries. Based on the 1891 census, population living in cities over 20,000 in New Zealand was about 28.4 %, while in Australia it was 40% (the same dynamics was true for cities over 10,000).[25] The urbanization pattern in New Zealand was quite different from that in Australia or elsewhere. One major distinction between the urban geography of New Zealand and other countries is the absense in New Zealand of a megapolis (population exceeding 1,000,000), largely due to New Zealand's small total population. The high rate of population growth in New Zealand up to 1911 permitted a substantial increase in the proportion of the population without any increase in the concentration of the population[26]. Low density in the cities and detached or semi-detached dwellings represented a completely different picture from that in the big European cities, which meant that the spread of disease would not happen as quickly and the incidence of diarreahl diseases would not be as great. Despite that, urban-rural differences in mortality did exist in New Zealand till about 1920.

The negative effect of urbanization on health (infant mortality) is often referred to in the literature as "urban penalty," which basically implies much higher infant mortality rates

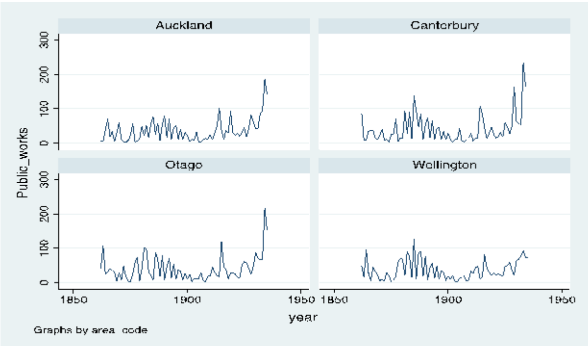
[23] Pool, 2002
[24] Pool and Bedford, 1997
[25] Gibson C., (1973), "Urbanization in New Zealand: A Comparative Analysis," p.72
[26] Gibson C., (1973), "Urbanization in New Zealand: A Comparative Analysis," p.83

in urban than rural areas, and therefore the price one have to pay for an opportunity to earn higher wages.

The existence of an "urban penalty" has been widely acknowledged by the American and European literature on mortality transitions. Generally, the excess urban mortality diminishing from the late 19th century onwards with the improvement of diet, public health measures, and overall living standards. For example, Australian crude death rates fluctuatied by up to 20/1000 until 1870's, henceforth there was a steady decline with a general reduction in the magnitude of year-to-year variations[27]. The US sustained mortality decline also commenced in the early 1870's, greatly furthered by the construction of waterworks and sewers and other public health measures[28].

In New Zealand, "urban penalty" existed at least during 1887-1907, after which the gap between urban and provincial rates has shrunk and practically disappeared after 1920[29]. Improvements in infrastructure, initiated by greater per capita real public works expenditure led to establishments of sewerage and water works systems. Sewerage systems were completed in Dunedin in 1908, Wellington in 1899 and Auckland in 1914. Christchurch's system was finished first, in 1882, but a high-pressure city-wide water supply only arrived in 1909 (argument #5). With fertility and infant mortality rapidly falling in 1880's, per capita real public works expenditure experienced an increase around the same time. With the introduction of refrigerated shipping and the need of a better infrastructure in place the expenditure boomed, which was followed by the 1890's decline. Liberal government's initiations in 1930 have led to an increased spending on public works projects, which stimulated healthier and safer urban environment.

Figure 10. Per capita public works expenditure in real values, 1862-1940



Now that we have discussed some of the major determinants of infant mortality in the context of New Zealand social and economic environment, with the hypotheses outlined in section II in mind, we proceed to quantitative analysis.

III. Methods and Modelling

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27 Taylor R., Milton L., (1998), "The Australian mortality decline: all-cause mortality, 1788-1990," p.28

28 Haines, Michael R. (2001). "The Urban Mortality Transition in the United States, 1800-1940."

29 Appendix 1, Figure 4.

This part corresponds to hypothesis testing that requires quantitative analysis. Since our data has large T and small N, certain degree of time series persistence could cause a potential bias. We begin with pretesting the series for any structural change that might have caused non-stationarity, both panel (Hadri (2003) Lagrange Multiplier (LM) and Levin, Lin and Chu (2002)) and individual unit root tests (both DFGLS and standard Dickey-Fuller procedures) were undertaken with one (Zivot and Andrews, 1992) or two breaks (Clemente-Montanes-Reyes, 1998) considered in individual series. To further explore provincial differences identified in the analytical section, we proceed to analysis in STAMP in order to model socio-economic and demographic variables either univaritately or multivariately without explanatory variables to identify any common/similar features among provinces. Finally, we test hypotheses by building a structural equation model in a panel setting that utilizes the framework and mechanisms from theory to establish the directions of the causal links.

i. Univariate analysis

In order to estimate a model using structural equation modelling technique, some standard unit root pretesting is needed to explore the time series properties of the data. Besides, identification of the data outliers and breaks can confirm or refute previous assumptions on the timing of changes in some series. Before estimation, the variables were transformed into log levels to satisfy the normality conditions. Hadri (2003) Lagrange Multiplier (LM) and Levin, Lin and Chu (2002) tests were utilized to test for stationarity in the panel setting. The Hadri LM panel test was used to control for the cross-sectional dependence and fixed effects. LLC test is a standard test for the common unit root process across panels (assumes the same AR (1) coefficient, but allows for individual and time effects) that was utilized for comparison.

Table 1 reports both test statistics. Common unit root test LLC test indicated the rejection of the null hypothesis in the panel setting meaning that the panels are stationary for all variables. Hadri LM statistics only identified two variables for which all panels are stationary: female marriage rate, public works and health expenditure per capita in real terms the rest showed the rejection of stationarity for all panels still allowing some of them to be stationary. To summarize, pooled statistics identified which series exhibit stationarity and which non-stationarity.

Table 1. Panel unit root tests (log-levels), 1872-1940

Panel variable	Hadri LM (removed means & robust case) Z-stats	Levin Lin Cheuing Adjusted t-stat* Cross-sectional means removed
Infant mortality rates	9.8993** (trend)	-7.5034** (trend)
Urban proportion	25.5558 ** (trend)	-2.8568** (trend)
Female marriage rate	-28.1593 (no trend)	-3.3943** (no trend)

Public works expenditure per capita	-0.9392 (no trend)	-13.5401** (no trend)
Health expenditure per capita	-0.4815 (no trend)	-9.5691** (no trend)
Real wages	8.4837** (trend)	-3.7731** (trend)
Temperature	6.6788** (no trend)	-1.9282** (no trend)
Female/male enrolment ratio	11.7554 ** (no trend)	-5.52** (no trend)
GFR (general fertility rate)	15.2097** (trend)	-5.894* (no trend)

Note: Hadri LM - Ho: all panels are stationary, H1: some panels have a unit root; LLC - Ho: common unit root, H1: panels are stationary; ** indicates rejection of the null at the 1 % level of significance.

To verify the robustness of the above results, individual unit root tests, both DFGLS and standard Dickey-Fuller procedures, were undertaken (based on Hadri LM results). DFGLS (GLS approach to testing an autoregressive unit root) is considered to be more efficient in terms of small sample size properties and power. For the series that showed to be non-stationary, Zivot and Andrews unit root statistics was used to establish stationarity in the presence of structural breaks. Some of the identified non-stationary series became stationary after accounting for the break in the series (urban proportion and real wages).

Table 2. Unit root test results (DFGLS, DF/ADF, Zivot and Andrews)

	Infant Mortality		Urban Proportion			Real Wages			Temperature		Early marriage	
Province	DFGLS	DF/ ADF	DFGLS	DF/ ADF	ZA	DFGLS	DF/ ADF	ZA	DFGLS	DF/ ADF	DFGLS	DF/ ADF
Auckland	VV*	VV*	VV*	VV*	-	VV**	VV*	-	V**	V**	XX	V*
Canterbury	VV**	VV**	XX	XX	V’ (both: 1894)	XX	XX	V’ (both: 1900)	V**	V**	XX	V*
Otago	VV**	VV**	XX	VV*	V’ (both: 1894)	VV**	VV*	-	V**	V**	XX	V*
Wellington	VV**	VV**	XX	XX	V’ (both: 1895)	VV*	VV**	-	V*	V*	XX	V*

Note: v – indicates that the series is stationary, vv – trend stationary, v’ – the series is stationary with the break in trend and/or intercept, x –nonstationary, x’ – the series is non-stationary with a break, xx – non-stationary with a trend.

The results of the various unit root tests generally generate similar results (DFGLS and ADF/DF statistics). Female enrolment ratio and GFR appeared to be non-stationary even after accounting for a single break in the series. We implemented another unit root test that allows for single and double mean shifts in the series (Clemente-Montanes-Reyes, 1998). The model can include both the additive outlier (AO) and the innovational outlier (IO) schemes.

Table 3. Zivot and Andrews and Clemente-Montanes-Reyes unit root tests

Provincial results	Female/male enrollment ratio	GFR: full sample	GFR (restricted

									sample:1872-1934)
	DFGLS	DF/ADF	Zivot &Andrews	CMR: Optimal break point	DFGLS	DF/ADF	Zivot & Andrews	CMR: Optimal breakpoint	DF/ADF (no constant)
Auckland	X	X	X(1884 trend)	**V (IO model, single mean shift: 1918 breakpoint)**	X	X	X(1886 intercept)	X' (1891, 1920 AO)	V**
Canterbury	X	X	X(1928 both)	**V (IO model, single mean shift: 1925 breakpoint)**	X	X	X(1900 both)	X'(1888, 1928 AO)	V**
Otago	X	X	X(1900 intercept)	**V (IO model, double mean shifts: 1875 and 1926 breakpoints)**	X	X	X (1901 both)	X' (1883, 1912 IO)	<1930 V*
Wellington	X	V**	-	-	VV**	VV**	-	-	-

Note: v – indicates that the series is stationary, v' – the series is stationary with the break in trend and/or intercept, x – nonstationary, x' – the series is non-stationary with a break

The general fertility rates were found to be non-stationary for most provinces, Wellington was an exception (the series turned out to be trend-stationary). The unit root test results, even after including one or more breaks, still inform us of non-stationarity of the fertility series. Despite what the tests tell us, the fertility series (Figure 5) are clearly declining and undergoing a transition with very little chance of hyper fertility in the post 1900's period. (given that New Zealand went through a demographic transition, adopting European pattern). Therefore, we restrict our sample to end date 1935 (to control for the series increase in 1930s), and run the unit root tests again for each province. Given that the end date for public works and health expenditure series is 1935, running a unit root test on a restricted sample seems appropriate. The DF tests with no constant and zero lags identified the three series stationarity. With these time-series properties established, we proceed to model formulation and building.

ii. *Time-series analysis using STAMP*[30]

In this section, we model socio-economic and demographic variables either univaritately or multivariately without explanatory variables to identify any common/similar features among provinces. We start with socio-economic variables by univariately decomposing each series that showed to be nonstationary/trend-stationary into several unobserved components. We utilize multivariate modelling of the key demographic variables to observe any commonality present across provinces.

We start our analysis with univariate modelling of our socio-economic variables since some of the provincial series do not exhibit similar features to be modelled multivariately. Table 4 presents estimation results for real wages, urbanization and female education.

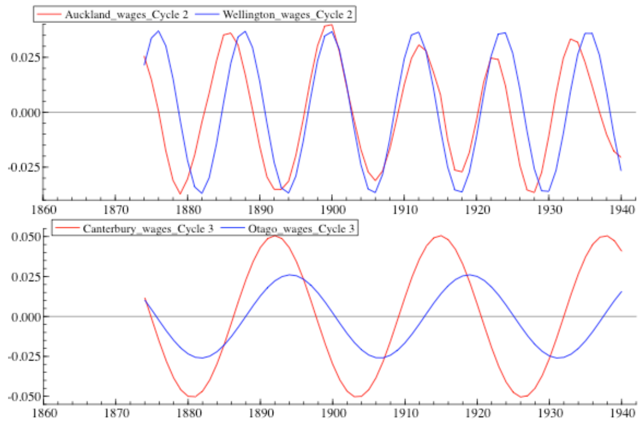
Table 4. Estimation results, unobserved components

[30] "STAMP (**S**tructural **T**ime Series **A**nalyser, **M**odeller and **P**redictor) is a statistical / econometric software system for time series models with unobserved components such as trend, seasonal, cycle and irregular". - http://stamp-software.com/

Model	Auckland	Canterbury	Otago	Wellington
Real wages model: $y_t = \mu_t + \psi 1_t + \psi 2_t + \varepsilon_t$, where μ_t is the trend, $\psi 1$ - short cycle, $\psi 2$ - medium cycle, ε_t-irregular component. ε_t~ NID (0, σ^2_ε), t=1874,…,1940.	μ_{1940}= 118.76**, β_{1940}= -0.71** (yearly %growth), *a* =1.94 (% of trend), Level – stohastic , slope – fixed; Rd^2=0.34, H(21)=0.5, Q(13,6)=2.796	μ_{1940}= 119.2**, β_{1940}= -0.021 (yearly %growth), *a* =5.05(% of trend), Level- fixed; slope stochastic Rd^2=0.21, H(21)=0.19, Q(13,6)=7.09	μ_{1940}= 96.97**, β_{1940}= -0.28** (yearly %growth), Level break: z_{1886}=0.151**; *a*=2.6 (% of trend), Level fixed, slope - stochastic Rd^2=0.4, H(21)=0.19, Q(13,6)=7.67	μ_{1940}= 113.87**, β_{1940}= -1.43 (yearly %growth), *a*=3.71 (% of trend); Level fixed, slope - stochastic Rd^2=0.32, H(21)=0.23, Q(12,5)=6.3
Urbanization model: $y_t = \mu_t + \psi 1_t + \psi 2_t + \varepsilon_t$, where μ_t is the trend, $\psi 1$ - short cycle, $\psi 2$ - medium cycle, ε_t-irregular component. ε_t~ NID (0, σ^2_ε), t=1874,…,1940. **For Wellington:** $y_t = \mu_t + \lambda w_t + \varepsilon_t$, w_t - intervention: takes the value one at the time event occurs and is zero otherwise; ε_t- irregular component.	μ_{1940}= 38.54**, β_{1940}= 1.26 (yearly %growth), *a* =12.72 (% of trend), Level – fixed , slope – stohastic; Rd^2=0.35, H(21)=0.39, Q(14,6)=6.96	μ_{1940}= 52.45**, β_{1940}= 0.33 (yearly %growth), *a* =9.76 (% of trend), Level – fixed , slope – stohastic; Rd^2=0.096, H(21)=0.48, Q(14,6)=8.22	μ_{1940}= 50.92**, β_{1940}= -1.09 (yearly %growth), *a* =6.45 (% of trend), Level – fixed , slope – stohastic; Rd^2=0.15, H(21)=0.138, Q(14,6)=5.65	μ_{1940}= 47.99**, β_{1940}= 0.511 (yearly %growth), Level – stohastic,slope – fixed Outlier w(1910)= - 0.05 Rd^2=0.063, H(21)=0.69, Q(9,7)=9.65
Education model: $y_t = \mu_t + \lambda w_t + \varepsilon_t$, w_t - intervention: takes the value one at the time event occurs and is zero otherwise; ε_t- irregular component.	μ_{1940}= 0.86**, β_{1940}= 1.34 (yearly %growth), Oulier: w_{1877}=-0.07558; Level – fixed , slope – stohastic; Rd^2=0.10, H(21)=0.16, Q(9,7)=3.82	μ_{1940}= 0.89**, β_{1940}= 1.57* (yearly %growth), Level – fixed , slope – stohastic; Rd^2=0.028, H(21)=1.4, Q(9,7)=5	μ_{1940}= 0.878**, β_{1940}= 1.522* (yearly %growth), Level – fixed , slope – stohastic; Rd^2=0.088, H(21)=0.98, Q(9,7)=3.5	μ_{1940}= 0.86**, β_{1940}= 1.56* (yearly %growth), Level – fixed , slope – stohastic; Rd^2=0.23, H(21)=0.48, Q(9,7)=7.2

Real wage series were found to exhibit cyclical behaviour with short and medium length cycles. Auckland and Wellington had similar regular cycles (similar damping factor and frequency), with Wellington’s cycle leading throughout most of the period (except during mid 1890’s-1920):

Figure 11. Real wages, regular cycle components



Canterbury and Otago experienced regular medium length cycles with different frequences and amplitudes. Otago's real wage series identified a break in the level in 1886. The real wage irregular components are highly correlated between Auckland and Wellington (correlation coefficient is 46%), and between Auckland and Otago (about 30%). This means that shocks were common between those provinces, or the series responded in the same way to some irregular unobserved effect. We would expect the shocks to have North and South similarities.

Urban proportion cycles were quite irregular for all three provinces, serial correlation was best resolved with variation in the level of the series rather than with an inclusion of a cycle component for Wellington. Urban proportion's provincial shocks are significantly correlated across all four provinces, with Canterbury and Otago being almost perfectly correlated (correlation coefficient is 83%). Education was best modelled with the fixed level, stohastic slope and irregular component. The model fit was not great, which means that other components or explanatory variables should be included to achieve a greater explanatory power. Irregular disturbances of education variable are highly correlated between Auckland and Wellington, Canterbury and Otago, and Canterbury and Wellington.

Given that the model is well specified, the irregular shocks reflect events that are independent of time and are completely random (the part that could not be described by the variations in the slope, level or cycle components). If the model fit is not great, the commonality of the shocks possibly captures some common explanatory variation that can be modelled by controlling for additional explanatory variables.

We continue to multivariate modelling of the key demographic variables (infant mortality, fertility and early marriage rates) in the proposed framework. We start with infant mortality series that represent the number of infant deaths per 1,000 live births in the respective population of each of the four provincial districts. We build a multivariate BSM (basic structural model) for the four infant mortality series. Our multivariate BSM consists of full variance matrices for the disturbance vector driving the unobserved component vectors. The model includes fixed level (does not depend on t), stochastic slope, interventions and irregular component[31]. Based on the estimation results, the projected future value of infant death rates per 1,000 live births are common across provinces, with rates being slightly higher in Canterbury and Otago. The convergence of infant mortality by 1940 is universal. The change in slope or yearly % decline rate is only identified as significant in Otago, and not significant elsewhere. The timing of the outliers varies across provinces, with the common outlier in 1930 for Otago and Wellington. The outliers are discussed in more detail later in this section.

Table 5. Infant mortality series estimation results, unobserved components

Provincial infant mortality rates	Estimation results, state vector anti-log analysis at period 1940
Auckland	μ_{1940} = 29.5594**, β_{1940} = -1.52 (yearly %growth), Std. error=0.15; outliers: w_{1864} =0.5977**, w_{1880} = - 0.4296**; Rd^2=0.51, N=6.7, H(23)=0.24, Q(9,7)=5.4778
Canterbury	μ_{1940} = 30.11**, β_{1940} = -1.64 (yearly %growth), Std. error=0.14; outliers: w_{1869} = - 0.429, w_{1871} = - 0.375**; Rd^2=0.553, N=1.2, H(23)=0.588, Q(9,7)=6.61
Otago	μ_{1940} = 30.11**, β_{1940} = -1.42* (yearly %growth), std. error=0.14; outliers: w_{1878} = - 0.6392**, w_{1892} = - 0.583**, w_{1930} =0.63992** Rd^2=0.722, N=0.052, H(23)=1.2, Q(9,7)=13.3
Wellington	μ_{1940} = 29.8363**, β_{1940} = -1.23 (yearly %growth); outliers: w_{1883} = - 0.42869**, w_{1930} = 0.8863**; Rd^2=0.635, N=0.50, H(23)=0.542, Q(9,7)=11.292

*,** based on a two sided test at 5 and 1 % significance level

The estimated variance/correlation matrices represent the irregular and slope disturbances (matrix order: Auckland, Canterbury, Otago, Wellington):

$$\hat{\Sigma}_{\zeta} = \left(\begin{array}{cccc} 2.53e^{-5} & 0.28 & 0.84 & 0.19 \\ 7.24e^{-6} & 2.69e^{-5} & 0.75 & 0.99 \\ 9.67e^{-6} & 8.86e^{-6} & 5.22e^{-6} & 0.69 \\ 8.28e^{-6} & 4.37e^{-5} & 1.35e^{-5} & 7.33e^{-5} \end{array} \right)$$

[31] $y_t = \mu_t + \lambda w_t + \varepsilon_t$, where $\mu_t = \mu_{t-1} + \beta_{t-1}$, $\beta_t = \beta_{t-1} + \zeta_t$ - trend component; w_t - intervention: takes the value one at the time event occurs and is zero otherwise; ε_t - irregular component.

$$\hat{\Sigma}_{\varepsilon} = \begin{pmatrix} 0.0171 & 0.329 & 0.25 & 0.4386 \\ 0.005 & 0.016 & 0.3794 & 0.5715 \\ 0.004 & 0.006 & 0.0185 & 0.26 \\ 0.008 & 0.010 & 0.005 & 0.02 \end{pmatrix}$$

We can observe that the disturbances' correlations for the slope components are much higher than for the irregular, variances are however much smaller for the slope component disturbances (level disturbances were constrained to be zero). The slope disturbances are almost perfectly correlated for Canterbury and Wellington pair, correlation is high among the following pairs: Auckland and Otago, and Otago and Canterbury. For the irregular component disturbances, the highest correlation is between two pairs: Canterbury and Wellington, and Auckland and Wellington. No deviant behaviour is found, all correlations are found to be positive.

Figure 12 identifies province specific plots of level plus intervention effects and irregular components. The 1864 outlier led to an increase in infant mortality in Auckland, which is likely attributed to an increased number of deaths from infectious diseases such as small pox. The outliers in 1869 and 1871 in Canterbury coincided with the Contagious Disease Act in 1869 and 1871 Vaccination act. The outlier in 1930, which led to a considerable increase in the number of infant deaths in Otago and Wellington, is associated with the beginning of economic depression in 1930s and heavy migration outflows.

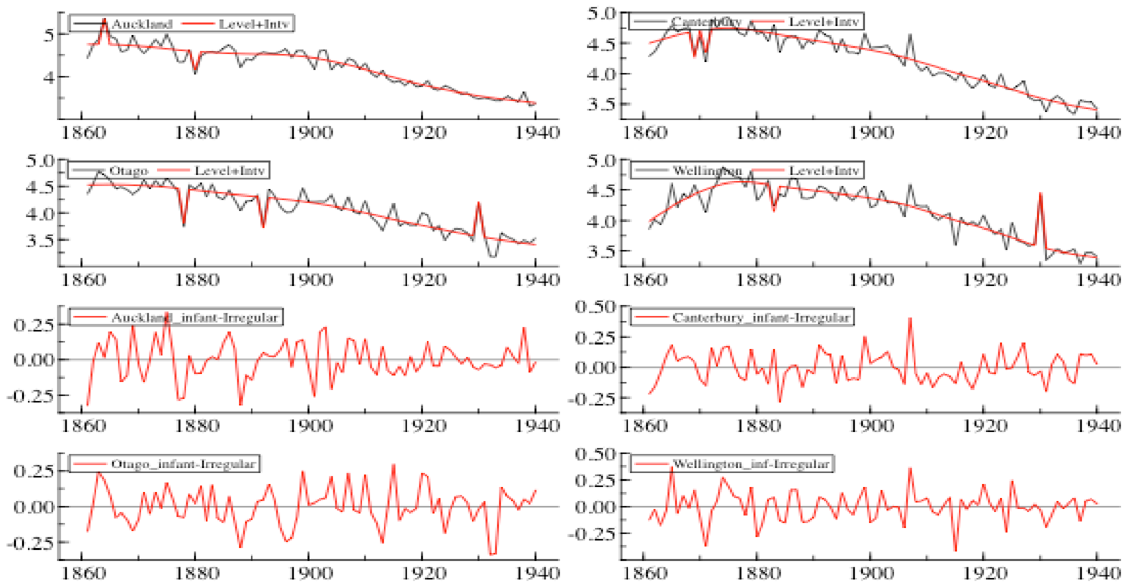
Another significant outlier in Otago in 1892 could be attributed to legislation changes that were affecting working conditions of the minority. In 1892 Factories Act provided stringent hygiene rules in specified workplaces, the impact, however, was immediately offset by 1893 measles epidemic.

The model outliers pick up the very large residuals that are of deviant behaviour. It is generally difficult to establish how genuine those outliers are, since historical data comes with the great deal of uncertainty of the estimates. The outliers could also reflect the sudden short-term changes (policy changes, epidemics) that often do not lead to permanent changes due to other events that offset those changes. Statistically, controlling for outliers is important if we want our estimates to be sound.

The model fits the data quite well (the results identify high Rs-squared), with no serial correlation identified in the series. The patterns of infant mortality decline seem to vary across provinces. The series experience different trending behaviour and the timing of structural change also does not seem to be common.

In Auckland, for instance, once we control for 1864 outlier, the 1870's infant mortality decline becomes non-existent, with the fastest changes occurring in 1900's. The infant mortality transition both in Canterbury and Wellington seems to occur around 1880. Otago is the only province, where decline happens earlier than 1880: statistically significant yearly slope decline of 1.8% means the series is declining throughout the whole 1861-1940 period.

Figure 12. Multivariate BSM unobserved components graphs, infant mortality



The “early” marriage is defined as the number of women ages 16-24 that were married per 100 of females of that age-group (used age-standardized values). Multivariate structural model for the early marriage constrains level to be fixed and allows for a stochastic slope and an irregular component. Similarly to infant mortality results, slope estimators of marriage series identify that the highest yearly decline occurred in Canterbury.

Table 6. Nuptiality series estimation results, unobserved components

Provincial early marriage rates	Estimation results, state vector anti-log analysis at period 1940
Auckland	μ_{1940} = 21.28**, β_{1940} = - 2.86* (yearly %growth), Std. error=0.01; Rd^2=0.80, H(21)=1.69, Q(9,7)=2.6
Canterbury	μ_{1940} = 16.02**, β_{1940} = - 4.12* (yearly %growth), Std. error=0.018; Rd^2=0.76, H(21)=1.62, Q(9,7)=1.49
Otago	μ_{1940} = 14.94**, β_{1940} = -2.82* (yearly %growth), Std. error=0.027; Rd^2=0.64, H(21)=0.34, Q(9,7)=8.31
Wellington	μ_{1940} = 19.1**, β_{1940} = -2.45* (yearly %growth), Std. error=0.013; Rd^2=0.69, H(21)=0.29, Q(9,7)=3.07

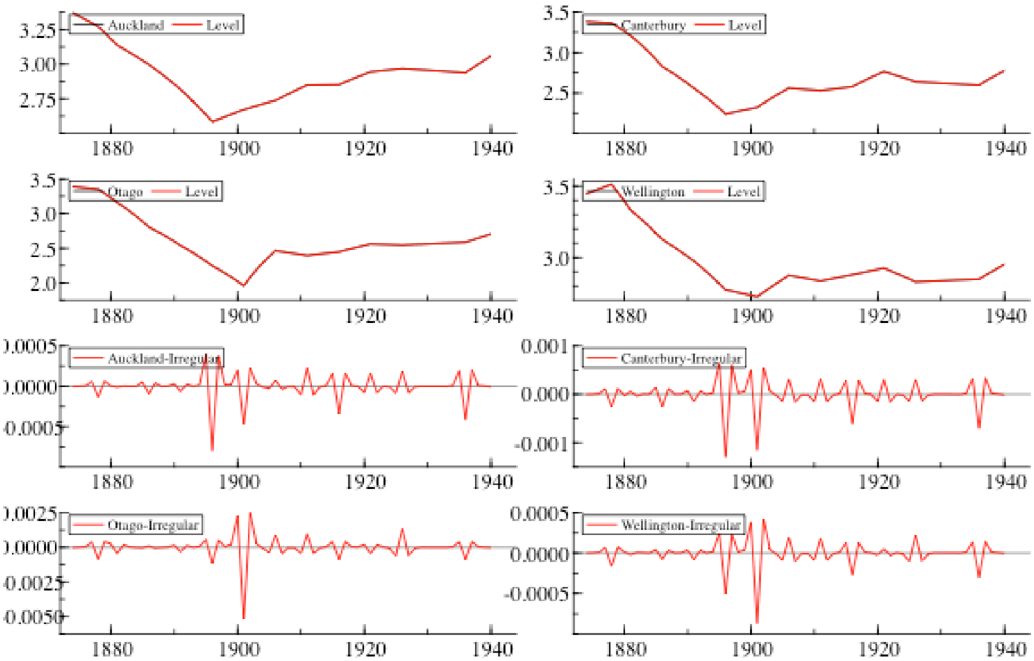
As before, we estimate variance/correlation matrices for the irregular and slope disturbances (rows and columns in the same order: Auckland, Canterbury, Otago and Wellington). The slope variance disturbances are again much higher than for irregular components.

$$\hat{\Sigma}_{\zeta} = \begin{pmatrix} 0.00011 & 0.6256 & 0.0523 & 0.439 \\ 0.00012 & 0.0003 & 0.59 & 0.79 \\ 1.559e-5 & 0.0003 & 0.0007 & 0.7151 \\ 6.641e-5 & 0.0002 & 0.00027 & 0.00019 \end{pmatrix}$$

$$\hat{\Sigma}_{\varepsilon} = \begin{pmatrix} 6.13e-7 & 0.9118 & 0.4217 & 0.766 \\ 9.69e-7 & 1.843e-6 & 0.59 & 0.9264 \\ 9.379e-7 & 2.287e-6 & 8.069e-7 & 0.8485 \\ 3.785e-7 & 7.938e-7 & 1.521e-6 & 3.984e-7 \end{pmatrix}$$

It is clear that the correlations of irregular components' disturbances are very high, which indicate commonality of the unexplained random shocks in the proportion of married series. Apart from that, the disturbance variances are extremely small, implies very little disturbance left unexplained. At the same time the model fit is very high. The fact that the series itself were heavily interpolated, some degree of distortion might have taken place. The irregular patterns, though, are quite interesting. Figure 13 identifies two similar patterns: Auckland-Otago, and Canterbury-Wellington. Some common disturbance took place in 1890's – early 1900's, after which the irregular series went back to fluctuating around zero.

Figure 13. Multivariate early marriage series BSM unobserved components graphs



In the literature, fertility is hypothesized to be directly affecting infant mortality. Analyzing the series in the multivariate setting without explanatory variables gives us some perspective on time-series properties of the data and the interactions among the four provinces. The multivariate BSM for general fertility series (GFR – defined as a number of births over the number of women of childbearing age, 15-44) allows level and slope to vary stochastically (unconstrained).

Table 7. Fertility series estimation results, unobserved components

Provincial fertility rates	Estimation results, state vector anti-log analysis at period 1940
Auckland	μ_{1940} = 95.8**, β_{1940} = - 3.59* (yearly %growth), Std. error=0.047; Rd^2=0.079, H(21)=2.8, Q(9,7)=2.08
Canterbury	μ_{1940} = 84.92**, β_{1940} = - 5.25* (yearly %growth), Std. error=0.05; Rd^2=0.12, H(21)=4.15, Q(9,7)=1.25
Otago	μ_{1940} = 77.5**, β_{1940} = -4.62* (yearly %growth), Std. error=0.1; Rd^2=0.27, H(21)=13, Q(9,7)=2.86
Wellington	μ_{1940} = 86.1**, β_{1940} = -4.17* (yearly %growth), Std. error=0.11; Rd^2=0.51, H(21)=16, Q(9,7)=2.53

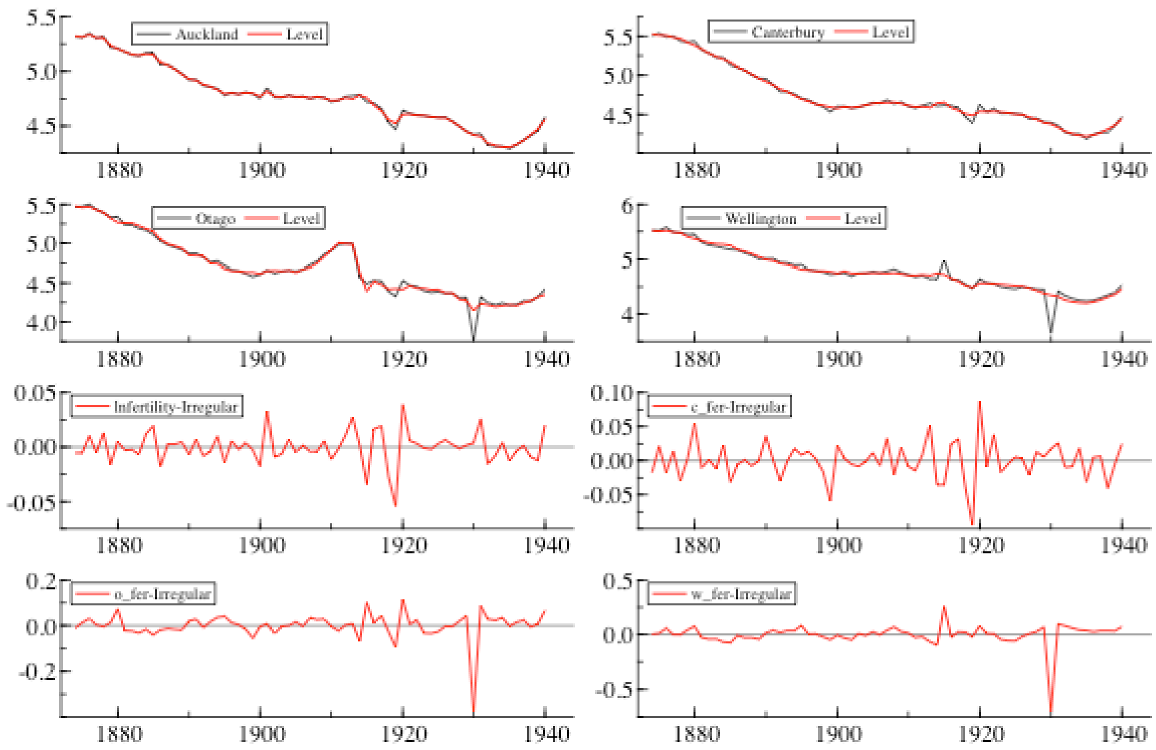
The level disturbances variance/correlation matrix identifies high positive correlations between Auckland and Canterbury, Auckland and Wellington, and Canterbury and Wellington. Thus, whatever the unexplained part is, its effect is practically the same for those provincial pairs. The slope disturbances are identical across all four provinces. Disturbances of the irregular components seem nearly identical for Otago Wellington pair. From Figure 14, the 1930 outlier is not explained by the model in neither series (Otago or Wellington), consequently gets picked up by the irregular disturbances.

$$\hat{\Sigma}_{\eta} = \begin{pmatrix} 0.00011 & 0.8053 & 0.1771 & 0.9966 \\ 0.00047 & 0.0003 & -0.44 & 0.851 \\ 0.00042 & -0.0005 & 0.0004 & 0.09518 \\ 0.001 & 0.00044 & 0.00019 & 0.00088 \end{pmatrix}$$

$$\hat{\Sigma}_{\zeta} = \begin{pmatrix} 9.029e-05 & 1 & 1 & 1 \\ 0.00013 & 0.00019 & 1 & 1 \\ 0.00012 & 0.00017 & 0.00016 & 1 \\ 0.00011 & 0.00016 & 0.0001469 & 0.00013 \end{pmatrix}$$

$$\hat{\Sigma}_{\varepsilon} = \begin{pmatrix} 0.0004 & 0.5371 & 0.3872 & 0.0171 \\ 0.00035 & 0.00096 & 0.40 & 0.05 \\ 0.00053 & 0.00081 & 0.0041 & 0.9078 \\ 3.805e-5 & 0.00016 & 0.0060 & 0.01068 \end{pmatrix}$$

Figure 14. Multivariate fertility series BSM unobserved components graphs



Modelling both demographic and economic variables using time-series methods provides us with greater understanding of the behaviour of each of those variables across provinces. Unobserved components allow us to separate changes in trends, slopes or cycles from irregular shocks, as well as identify any model outliers that might confirm the impact of certain events identified in the theory. Demographic literature identifies the turning point for infant mortality decline in 1870's. The rapid decline, however, was a consequence of a peak prior to that. In fact, 1875 was the only year when the infant rates went above 100 infant deaths per 1,000 live births, when deaths from respiratory and diarrhoeal diseases all reached record heights.[32] Therefore, apart from the peak in 1875, the decline was relatively gradual. Provincial data supports this more gradual decline in infant mortality. Empirical results showed that the infant rates in Otago were falling throughout the whole 1861-1940 period with 1.8% yearly decline. In Wellington, infant rates were, in fact, increasing in 1870's, and only in 1900's Wellington's infant rates reached the early 1860's level. We believe that post 1900 period identifies another stage of infant mortality decline that is much less affected by changes in fertility or nuptiality. The proportion of married women, ages 16-24, reported for 1876-1940 period, for all provinces identify a gradual decline till the end of 1890's, and then a slight increase in 1900's, which means that most changes occurred during the period prior to 1900. Decline in fertility also seemed to slowdown in 1900, remaining relatively constant, on average, thereafter. This gives us reason to believe that the nature of the decline prior to 1900 was different to post 1900 period, with various public health initiatives (Public Health Act of 1900, the Midwives registration Act of 1903-1904, Hospitals and Charitable

32 McLean (1964).

Institutions Act of 1909, Foundation of Plunket Society, 1907), improved infrastructure with an increased rate of technological change and economic growth.

This time-series section corresponds to the across province analysis, and the following section represents the within province analysis that utilizes structural equations to form a mechanism in a panel environment described earlier in the paper. This time-series section is an appropriate prelude to a more in depth model testing.

iii. SEM analysis

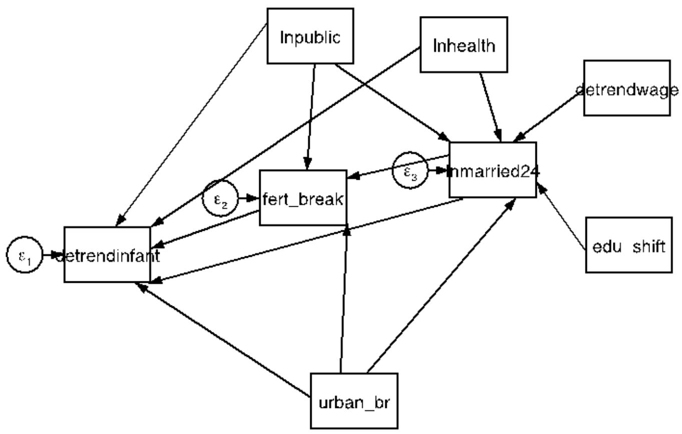
The conceptual model described in the earlier sections, together with hypothetical causal relationhsip between variables in the model are tested via structural equation modelling (SEM) technique, which appears to be quite powerful for analysis of causal links between endogeounous variables, and between endogenous and exogenous variables. Structural equation modeling has various advantages over the regular OLS model techniques: better estimates for bi-directional causal relationships without the bias inherent to OLS methods; breakdown of coefficients into direct, indirect and total effects; can deal with any type of variables such as linear, non-linear, and latent. The structural modelling procedure generally consists of four steps: model specification, model identification, model estimation, and model fit. Since, the conceptual framework was more or less formulated, the model identification uses two methods to determine identification of a structural model: order and rank conditions. The specification of the model has to be modified accordingly (constraining some parameters to zero or use of additional exogeneous variables) if the model is not identified (any two of the identification conditions violated). There exist three types of estimation techniques: maximum likelihood, GLS, and asymptotic distribution free. We carry out our model estimation using maximum likelihood estimation (ML), which maximizes the likelihood of obtaining the observed sample covariance structure. Multivariate assumption of normality should not be violated in this case. That said, it has been shown (e.g. Chou and Bentler, 1995) that ML estimation is more robust under a violation of normality than the other techniques. The last step identifies how model fits the data or how close the model-implied variance-covariance matrix is to the sample variance-covariance matrix.

The data set employed in estimation of a structural model comprises time series for the variables of interest, staionarity of each series is required for the validity of the estimated parameters (weak stationarity condition requires first and second moments to be independent of time). Earlier, we identified via various unit root tests which series are stationary, trend-stationary or stationary with breaks. The variables were modified accordingly, using information on the timing of breaks and the properties of trends derived in the *Univariate analysis section*. To achieve normality, we transformed the variables into log levels before any data manupaltion took place.

We begin with a proposed in the literature framework that identifies direct fertility effects and indirect effects of changes in the marriage pattern through fertility. The underlying rationale for the shift in the patterns of nuptiality is changes in the values of women and couples, which are, in turn, affected by social and economic changes.[33]

Socio-economic variables act as more remote determinants of the above mechanism. Initially, when we estimated a model that describes this mechanism, the model fit was poor (failed the LR test of model vs. saturated), as a result we explored the significance of the alternative paths. We found that urbanization has a direct effect on all three demographic variables; per capita expenditure on public health and public works directly affect infant mortality and the proportion of married females, ages 16-24, that also directly links to infant mortality.

Figure 15. SEM framework



LR test of model vs. saturated: chi2(20) = 19.75, Prob > chi2 = 0.4739

The schematic figure above identifies some interesting interactions. We tested several different specifications to detect a model that fits the observed data the best. The estimation results that recognize groups assume that model parameters are conditioned on covariances

[33] Pool I., Tiong J., *New Zealand Population Review, 15-1, 1989*; p. 49.

between structural and measurement errors to be equal across groups. We identify three endogenous variables and five exogenous variables, which comprise three estimated equations: fertility, infant mortality and the proportion of married females, ages 16-24 (proportion of those married over the total number of women, standardized by age).

In SEM, we are able to distinguish between direct, indirect and total effects of the exogenous variables. The direct causal fertility factors are the standardized proportions of married women (ages 16-24), urbanization and per capita expenditure on public works. While the effect of proportion married on fertility is universal, urbanization is significantly causal only in South Island (Canterbury and Otago), and public works expenditure significantly impacts fertility only in Canterbury with paths for other provinces not found to be significant. While the positive effect of the early marriage on fertility is consistent with previous assumptions and is part of the mechanism, urbanization is estimated to be increasing fertility in Canterbury and Otago, which is not something we would expect. However, New Zealand economy was highly pastoral and the farming sector has been dominating the economy throughout. The initial pastoral benefits were realized in the South and then transferred to the areas of the North Island. Even in 1900's the industrial production played a limited role, during 1880-1925 New Zealand's manufacturing was dominated by a handicraft production. Domesticity of women prevailed in New Zealand well into the twentieth century. In particular, in post 1914 period, the average age of marriage dropped and few married women worked outside their homes, increasing the likelihood of having more children than they would otherwise.

Infant mortality equation identifies the following direct effects: fertility, urbanization, public works and health expenditure per capita. The direct negative effect of fertility on infant mortality is highly significant in Auckland and Wellington. This gives us the impression that only provinces of the North Island reflect the hypothetical causal mechanism of infant mortality reduction by decline in fertility affected by changes in nuptiality. The decline in infant mortality in the South Island seem to be driven by socio-economic factors more so than in the North. For instance, increase in urban proportion would lead to an infant mortality decline in Canterbury and an increase in Wellington, and public health expenditure leads to significant reduction in infant moratlity in Otago.

Finally, the early marriage equation identifies real wages, urbanization, and female enrollments as significant causal factors for all provinces. Real wages have a negative impact on infant mortality in Auckland, Canterbury and Otago, the sign for Wellington is reversed. Controlling for other exogenous effects, the increase in urbanization and female enrollments would also lead to the reduction of the proportion of married females, ages 16-24. Per capita expenditure on health also has a direct negative effect on the proportion of early marriage in Auckland and Otago. Real wages, urbanization and female education are identified as significant driving factors of the changing nuptiality patterns in all provinces.

Table 8. SEM estimation results, Direct Effects

Endogenous	Exogenous	Auckland	Canterbury	Otago	Wellington

Fertility	The proportion of early marriage	(+)***	(+)***	(+)***	(+)***
	Urbanization	(+)	(+)***	(+)***	(-)
	Public Works	(+)	(+)***	(-)	(-)
Infant mortality	Fertility	(-)**	(-)*	(-)	(-)***
	The proportion of early marriage	(-)	(+)	(-)	(+)***
	Urbanization	(+)*	(-)***	(+)	(+)*
	Public Works	(-)**	(-)**	(-)*	(-)***
	Public Health	(-)*	(-)	(-)**	(-)
The proportion of early marriage	Real Wages	(-)***	(-)***	(-)***	(+)***
	Urbanization	(-)***	(-)***	(-)***	(-)***
	Female education	(-)***	(-)***	(-)***	(-)***
	Public Works	(+)***	(+)	(-)	(+)
	Public Health	(-)***	(-)	(-)**	(-)

*, **, *** significance level at 10, 5 and 1%, respectively

Socio-economic variables also affect fertility indirectly through nuptiality as described in the theoretical framework. Improved socio-economic environment (represented by real wages, urbanization, female education and public health) was driving the fertility decline which appears to be common across provinces (except for real wage effect in Wellington and public works in Auckland).

Infant mortality equation provides us with some interesting results: once we control for other socio-economic varibles the indirect effect (via fertility) of the proportion of early marriage is found to be negative. The reversed sign on nuptiality makes a case of the relative importance of inclusion of the socio-economic factors in the model, and complexity of the relationhsips between endogenous, exogenous and other endogenous variables, the effects of which we attempt to quantify (the proportion married enters infant mortality equation twice: both directly and indirectly).

Table 9. SEM estimation results, Indirect effects

Endogenous	Exogenous	Auckland	Canterbury	Otago	Wellington
Fertility	Real wages	(-)**	(-)***	(-)***	(+)***
	Urbanization	(-)**	(-)***	(-)***	(-)***
	Female education	(-)***	(-)***	(-)***	(-)***

	Public Works	(+)**	(+)	(-)	(+)
	Public health	(-)**	(-)	(-)**	(-)
Infant Mortality	The proportion of early marriage	(-)***	(-)***	(-)***	(-)***
	Real wages	(+)*	(+)	(+)	(+)
	Urbanization	(+)	(+)	(+)	(+)
	Female Education	(+)**	(+)	(+)	(+)
	Public Works	(-)**	(-)	(+)	(-)
	Public Health	(+)*	(+)	(+)	(-)

*, **, *** significance level at 10, 5 and 1%, respectively

Table 10 summarizes the total effects, we use those as a guide in confirming or rejecting the hypotheses we set out to test in the begining of this paper.

Starting with fertility, we confirm that female education played an important role as a fertility determinant. Education appears to be relatively more important driver of fertility than both real wage and the proportion of early marriage. But most importantly, education is the main factor that was driving the proportion of early marriage to decline, which further attests to the fact that the free compulsory schooling introduced in 1877 changed values relating to the enforcement of school attendance and served as a function of society's shifting attitudes to child labour, as evidenced in the factories act 1894. Other socio-economic determinants (e.g. urbanization, real wages, expenditure on public health) were also found as significant causal effects in the proportion of early marriage equation.

Going back to fertility equation, we find that an increase in the proportion of early marriage led to an increase in fertility across all provinces. The fact that the relationship between fertility and real wages is negative means that New Zealand was not in fact Malthusian at all during 1874-1934 period, and the children were perceived as an investment rather than the workforce. Urbanization caused fertility to decline, and investment in public infrastructure led to its increase in Canterbury. Health expenditure also played a certain role in fertility decline Auckland and Otago. Overall, socio-economic variables enter both fertility and the proportion of early marriage equations, however, there is an apparent causal relationship between these two endogenous variables. Taking all interactions and linkages into account, an analytical framework of fertility change is found to be valid for this time period (1874-1934).

The model for the infant mortality as the "main" endogenous variable (all other variables are causing it) is clearly complex but the two patterns can be identified. In the North Island, we have found evidence of the hypothesis put forward in the begining of this paper that fertility regulation via nuptiality change as a means of controlling reproduction was the main driver of infant mortality decline for the period 1873-1934. No such evidence can be found for the provinces in the South Island. More intensive urbanization and improved infrastructure led to lower infant mortality rates in Canterbury, while increased expenditure on health and greater public health initiatives attributed to an infant mortality decline in Otago.

Table 10. SEM estimation results, total effects (standardized coefficients)

Endogenous	Exogenous	Auckland	Canterbury	Otago	Wellington
Fertility	The proportion of early marriage	0.18244***	0.4914***	0.2990***	0.38616***
	Real Wages	-0.10332**	-0.70499***	-0.7574***	0.2626***
	Urbanization	(-)	-0.07933**	(-)	-0.191513*
	Female education	-0.3786***	-2.663***	-1.8699***	-1.161***
	Public Works	(+)	0.277**	(-)	(-)
	Health Exp	-0.009015**	(-)	-0.0474**	(-)
	R^2	13.51%	77%	39.2%	47.3%
Infant Mortality	Fertility	-0.7045***	(-)	(-)	-1.206***
	The proportion of early marriage	-0.419**	(-)	(-)	(+)
	Real wages	(+)	(+)	(+)	(+)
	Urbanization	0.2425***	- 0.18328***	(+)	0.3658*
	Female education	0.87***	(+)	(+)	(-)
	Public Works	-0.081***	-0.0545***	(-)	-0.0422*
	Health Exp	(-)	(-)	-0.125**	(-)
	R^2	36.36%	33.7%	17.52%	42.16%
Proportion of married	Real wages	-0.566***	-1.434***	-2.532***	0.680***
females, ages 16-24	Urbanization	-0.249***	-0.39239***	-0.59128***	-0.372***
	Female education	-2.0755***	-5.419***	-6.252***	-3.0069***
	Public Works	0.0566***	(+)	(-)	(+)
	Health Exp	-0.049***	(-)	-0.1586**	(-)
	R^2	60.1%	77%	60.9%	55%

*, **, *** significance level at 10, 5 and 1%, respectively
LR test of model vs. saturated: Chi^2(20) =19.75, Prob>Chi^2=0.4739

In this chapter we made an attempt to model the mechanism of infant mortality decline during 19th-mid 20th centuries for the four major New Zealand provinces. In the beginning we discussed some possible explanations and reasons for such a unique pattern of infant mortality decline in New Zealand, some hypotheses were extracted from extensive demographic references from Ian Pool and others. Due to complexity of the underlying mechanism of infant mortality decline at the time, we utilized SEM to establish causal links among both exogenous and endogenous variables. With this paper we do not attempt to criticize or undermine the earlier work, but rather add the more broad economic perspective backed up by quantitative results. The results of the estimated SEM are highly prelminary, greater explaratory analysis is needed to identify other possibilities.

IV. Conclusion

This paper contributes to a much broader understanding of the underlying mechanisms of infant mortality decline in New Zealand during the late 19th – mid 20th centuries. The unique background conditions of New Zealand determined some of the initial advantage in the survivorship of infants in the first year of life relative to other European countries. This advantage then persisted into the twentieth century. The factors affecting secular infant mortality decline elsewhere would not always be applicable for New Zealand. New Zealand demographic literature, especially Ian Pool's work, puts a great deal of emphasis on non-economic factors of this decline (fertility decline through nuptiality changes as the main mechanism of the infant mortality decline), assuming New Zealand economic environment to be relatively favourable and stable. In this paper, we slightly shifted the emphasis away from micro to macro factors and determinants of infant mortality. Availability of newly derived yearly socio-economic and demographic data allowed us to quantify testable hypotheses put forward in demographic literature. Given spatial aspect of this data, we were able to estimate and compare the results for the four major New Zealand provinces.

In the analytical part of this paper, we reviewed some existing literature on infant mortality decline and its causes in various European countries. While, there was no definitive answer, empirical evidence supports the idea that improvements in economic conditions in the 19th century were fundamental in the decline in death rates in the developed world. The mortality history of New Zealand is often considered as "unique" both in terms of its demographic and epidemiological transitions. From the demographic point of view the turning point for infant mortality decline was the late 1870's, because of the rapid decline in fertility due to changes in nuptiality patterns. From the economic point of view, the decline coincided with the beginning of refrigeration era, including social and economic benefits that came with it (increased expenditure on public works, rapid increase in real wages, social and education reforms etc.). The fact that infant mortality rates were declining throughout most of the 1861-1940 period indicates that the fertility and nuptiality changes (fertility reached approximately its replacement level and remained relatively constant and the proportion of married women, ages 16-24 experienced an increasing trend post 1900) did not contribute much to its post-1900 decline. The post-1900 infant rates continued to decline due to various public health initiatives (Public Health Act of 1900, the Midwives registration Act of 1903-1904, Hospitals and Charitable Institutions Act of 1909, Foundation of Plunket Society, 1907), improved infrastructure with an increased rate of technological change and economic growth.

The empirical part of the paper commenced with some standard unit root pretesting, superseded by univariate and multivariate analysis without explanatory variables. The analysis was of an exploratory nature identifying common cycles or slopes, or common irregular disturbances across provinces. We found some common business cycle activity in the wage series of Auckland and Wellington, with the irregular shock also being common in these two provinces. Canterbury's yearly rates of decline for all three demographic indicators were the highest among the other provinces. Overall, multivariate analysis did not identify any particular patterns across provinces, which seem to be different for different indicators.

Because of the complexity and interrelatedness of the underlying causes of infant mortality decline, we generated a structural equation model to assess the relative importance of those demographic and socio-economic determinants. Within SEM framework (the nuptiality->fertility->infant mortality mechanism), we estimated three equations: fertility, infant mortality, and the proportion married (nuptiality change). First of all, we found that socio-economic determinants all had a direct effect on each of these endogenous variables. Taking all interactions and linkages into account, an analytical framework of fertility change is found to be valid for the 1874-1934 period. From both fertility and infant mortality equations, it has been discovered that malthusian mechanisms did not operate in New Zealand. And, most importantly, North and South patterns could be recognized when assesing the infant mortality model. In the North Island, we have found evidence of the hypothesis put forward in the begining of this paper: that fertility regulation via nuptiality change (as a means of controlling reproduction) was the main driver of infant mortality decline for the period 1873-1934. No such evidence can be found for the provinces in the South Island, where more intensive urbanization and improved infrastructure led to lower infant mortality rates in Canterbury and greater public health initiatives attributed to an infant mortality decline in Otago.

Some hypotheses and assumptions were accepted or partially accepted, some did not find evidence for existence from this analysis. Essentially, the results recognize the differential importance of socio-economic factors on infant mortality in light of demographic transition in New Zealand. The created SEM can be further explored, given that alternative frameworks (with additional and recursive paths) can be equally valid. A more thorough examination can be undertaken for an across-province analysis. Future research may also consider incorporating nutrition measures (such as average heights) in our infant mortality model to achieve the more coherent understanding of the nature of its decline in New Zealand.

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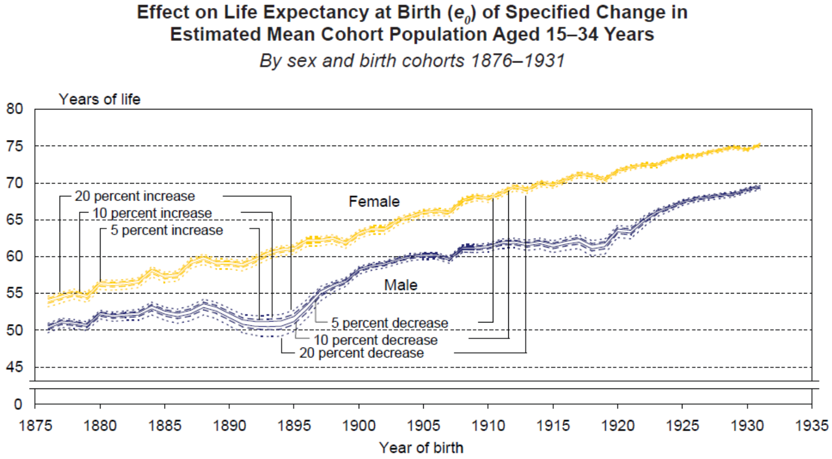
APPENDIX 1.

Figure 1



Source: Statistics New Zealand, (2006). Analysis of the cohort mortality.

Figure 2. Life expectancy at birth, males: Australia and UK

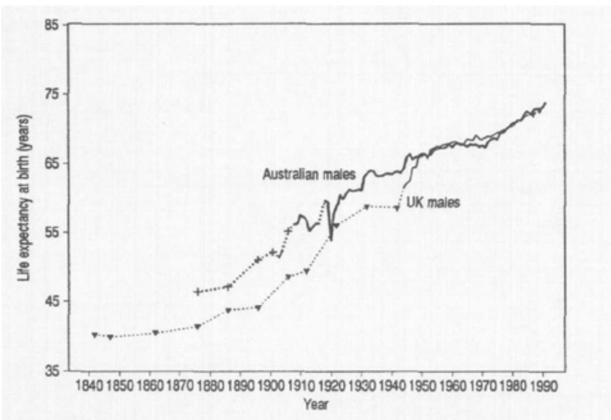


Figure 3. Life expectancy at birth, females: Australia and UK

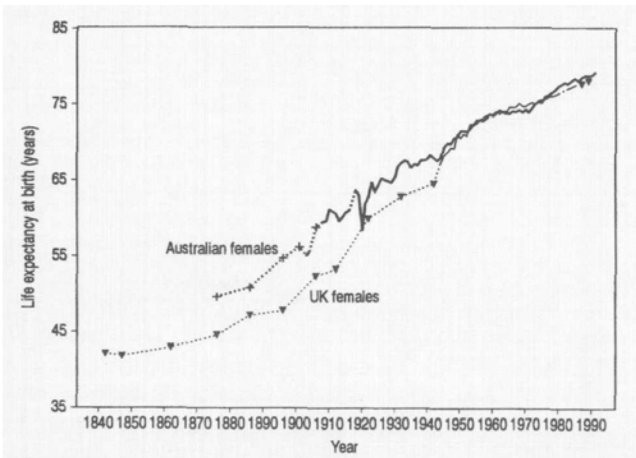
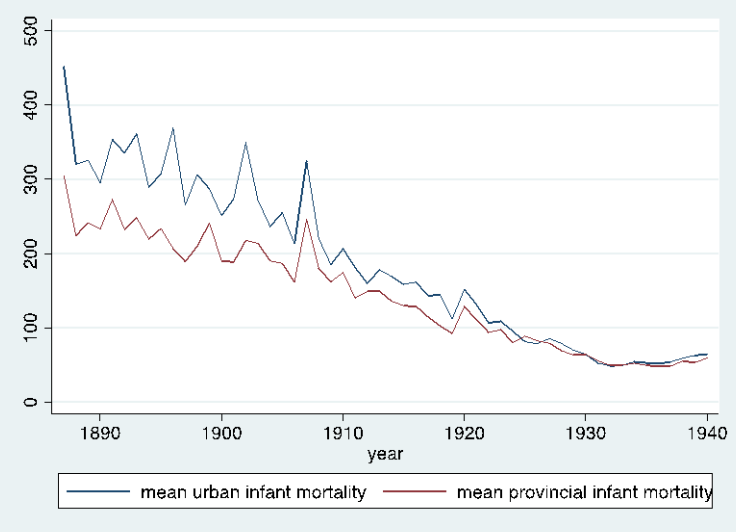


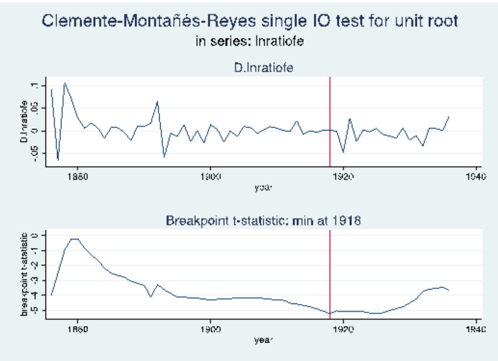
Figure 4. Average infant mortality rates (urban vs. provinicial) per 100,000 total population

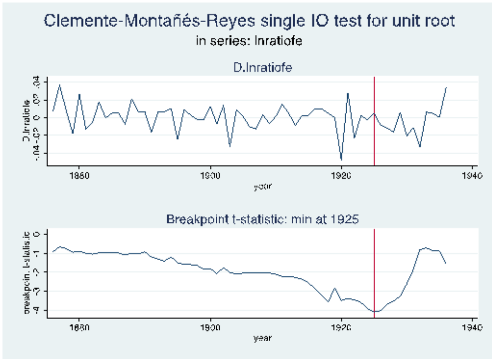


APPENDIX 2.

Table 1. Zivot and Andrews test (single break); Clemente-Montanes-Reyes unit root test with single and double mean shifts (female enrolment ratio)

Province	Zivot & Andrews unit root test	CMR: Optimal breakpoint	T-stats
Auckland	Trend: 1884	IO model: 1918**	-4.815<-4.270 (critical 5%) rejection of the null
Canterbury	Both: 1928	IO model: 1925**	-4.392<-4.270 (critical 5%) rejection of the null
Otago	Intercept break : 1900	IO model: 1876**, 1926**	-5.779< - 5.490 (critical 5%) rejection of the null





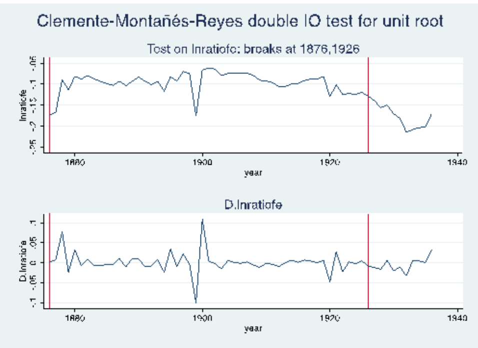
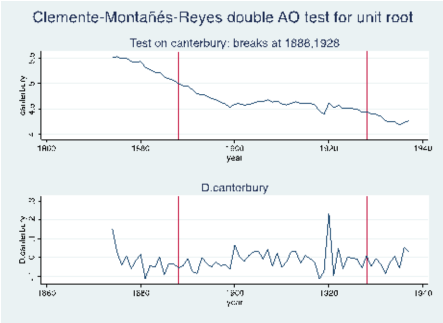
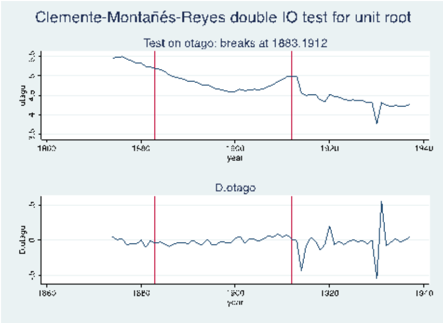


Table 2. Zivot and Andrews test (single break); Clemente-Montanes-Reyes unit root test with single and double mean shifts (the general fertility rate)

Province	Zivot & Andrews unit root test	CMR: Optimal breakpoint	T-stats
Auckland	Intercept break: 1886	AO model: 1891**, 1920**	-3.77>-5.490 (critical 5%) non-rejection of the null
Canterbury	Both: 1900	AO model: 1888**, 1928**	-3.717>-5.490 (critical 5%) non-rejection of the null
Otago	Both: 1901	IO model: 1883**, 1912**	-4.750>-5.490 (critical 5%) non-rejection of the null





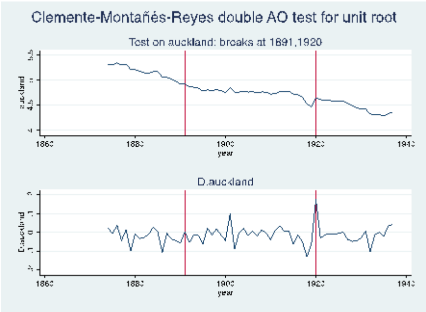


Table 3. Group-level goodness of fit statistics, SEM

Area code	N	SRMR*	CD**
Auckland	61	0.03	0.65
Canterbury	61	0.024	0.849
Otago	61	0.018	0.691
Wellington	61	0.046	0.643

*Standardized root mean squared residual
**The coefficient of determination