Three essays on Malaysian population ageing

by

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Abstract

Malaysia's ageing population is inevitable following the increase in life expectancy at birth and decrease in fertility rates over the last four decades (Mahari 2011). As a result of these demographic changes Malaysia is expected to become an aged nation by 2030—when the proportion of elderly people reaches 15% of the total population (Goh & Lai 2013). The elderly are less healthy than the young, hence an increase in the percentage of the elderly population will result in a greater demand for long term care services (Mafauzy 2000). Currently, the public long term care system in Malaysia is not up to such a challenge, given that policy related to long term care is not developed and the entitlements for public long term care programs are limited to destitute elderly people (Ong 2002). This issue has been extensively debated by researchers and there is a growing sense of urgency for public long term care policy action (Mafauzy 2000, Ong 2007, Dahlan et al. 2010, Li & Khan 2012). Nevertheless, none of the researchers have estimated the change in the Malaysian population structure, and the likely demand for long term care in the future. Such detail is valuable for government and would be useful in policy reform. This thesis aims to contribute to filling this gap. Three research papers have been prepared, each seeking in detail the changes in the Malaysian population and its population components (mortality, fertility and net international migration) over time. The last paper also examines how changes in mortality and disability affect long term care demand and costs in the future.

The first paper examines mortality forecasting methods for the Malaysian population. The comparison of mortality forecasting models is vital for identifying which of the models could provide more accurate forecasts. While the literature includes comparisons between independent and independent models (Lee & Miller 2001, Booth et al. 2005, 2006, Shang et al. 2011) and independent and coherent models (Hyndman et al. 2013), no comparisons between coherent models have been made. In this paper we include both the comparison between coherent models, and coherent models with independent models. The out-of-sample forecast errors of sub-populations' age-specific mortality rates and life expectancy at birth are evaluated and compared across five different projection methods, including coherent models—Poisson common factor (Li 2013) and product-ratio functional (Hyndman et al. 2013)—and their respective independent models—Poisson Lee & Carter (Brouhns et al. 2002) and functional time series (Hyndman

& Ullah 2007)—together with the original Lee & Carter (1992) model. We extend the applications of coherent forecasting models using data from a less developed country, Malaysia, where mortality trends are different. In addition, we include two types of coherency for Malaysian sub-populations, including gender as well as ethnicity.

The second paper forecasts each of the Malaysian population components—mortality, fertility and net international migration—in projecting the Malaysian age-specific sub-populations by gender and ethnicity. The stochastic cohort component projection framework from Hyndman & Booth (2008) is adopted for this purpose. Each of the population components are forecast separately and jointly between sub-populations using the functional independent model from Hyndman & Ullah (2007) and the product ratio coherent model from Hyndman et al. (2013), respectively. For the latter, in addition to gender coherence, we explored another possible type of coherency—that of developed-developing countries. The forecast of population components are then combined using the cohort component method to obtain a variety of Malaysian population forecast series. Out-of-sample sub-population forecasts are evaluated to determine the best model for long-term Malaysian population projections by age and gender.

The final paper studies the impact of population change on the Malaysia's government provided long term care programs. The number of people requiring long term care in Malaysia is projected up to the year 2040 using the multiple state method from Rickayzen & Walsh (2002). The method has been applied in developed nations (Leung 2004, Hariyanto et al. 2013) and a developing country (Bueno 2013). Rickayzen & Walsh's 2002 methods are extended in this paper to allow the estimation of mortality improvement based on Malaysian historical time-series data. The future long term care costs are also estimated, providing valuable information to policy makers if the current policy continues unchanged. In addition, the cost effectiveness of current programs is estimated and compared with an Asian developed nation, Japan. We make use of WHS (2002) survey data to estimate the health utility index for elderly living in public institutional care.

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Statement of Originality

This thesis complies with the standard of the Thesis by Publications format which follows the Macquarie University Thesis Submission Guidelines. I hereby certify that this thesis is solely the candidate's own research work and that it has not, nor has any part of it, been submitted for a higher degree to any other university or institution. The sources of information or material where the work of others have been utilised, are acknowledged in the thesis.

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Chapter 1

Introduction

1.1 Research Background

Given both a decline in mortality and a decline in fertility, the Malaysian population age-structure is undergoing major modifications—the percentage of the working-age population will decrease while the percentage of elderly[1] people will grow substantially over time, leading to population ageing. A growing number of elderly people poses a challenge to government, which has to adapt to meet their needs.

The existing Malaysian long term care policy encourages children to be responsible for their parents and provide informal care to them. Admission to public institutional homes is restricted to the destitute elderly whose income lies below a threshold[2], the majority of whom do not have family members to provide them with care. In 2012 about 0.09%[3] of the elderly population resided in the institutional homes provided under the public scheme. This percentage is minuscule in comparison to Japan, the oldest nation, in which 3% of those aged 65 and above were living in nursing homes (Mitchell et al. 2007).

[1]National Older Persons Policy (2011) defined elderly as people aged 60 years old and above. This is consistent with the current minimum retirement age for public and most private sector workers given in the Minimum Retirement Age Act (2012).

[2]Extremely poor with income less than MYR$499 (USD$123) per month (Economic Planning Unit 2014). The conversion of Malaysian Ringgit to US Dollars is based on `http://www.xe.com/currencyconverter` as at 23rd of September 2015. USD$1 is equivalent to MYR$4.0497.

[3]The Operational Assistant Director, Social Welfare Department indicated in 2012 that 2,084 elderly people were living in public residential care, with 1,847 of them living in residential care (Rumah Sri Kenanga) and 237 living in nursing home care (Rumah Ehsan) (Hargaemas 2012). The total elderly population 2012 was 2,438,500 (Hassan 2012).

Limited public long term care benefits together with a falling number of children available to provide informal care giving has resulted in an increase in demand for private nursing home care in Malaysia (Dahlan et al. 2010). At this moment, the costs of long term care giving are usually paid using the personal savings of the elderly (or their children) due to the absence of private long term care insurance in the market and the restricted nature of public programs. Without enough savings, the need for long term care imposes a burden on the elderly and their families. Similar situations arise in other developing countries, where population ageing is now beginning to emerge. In China, for example, the decrease in family size, as a result of its one-child policy has restricted traditional care giving by family members. This limitation, together with the risks associated with providing for long term care—broadly known as 'precautionary savings' by economists (Hubbard et al. 1995)—leads to higher savings among family members (Imrohoroglu & Zhao 2015). Too high a level of savings will affect productivity growth, with ultimately deleterious effects on the national economy.

One of the most important inputs that can be used to inform policy change in long term care is the estimate of the long term care demand. Kudrna et al. (2013) have suggested there are two important aspects in estimating demand for long term care—the uncertainty of the magnitude of change in the population and the evolution of disability levels by age. In order to address this first challenge, stochastic population projection methods are invaluable. Such methods use statistical models and historical data to measure the uncertainty of forecasts. Hyndman & Booth's (2008) model, for example, provides a statistical modelling framework that can forecast each of the demographic components (mortality, fertility and net international migration) and estimate the uncertainties associated with the forecast values. Each of the component forecasts with its future sample paths can be combined using the cohort component method to obtain population projections with prediction intervals. In order to deal with the second challenge, the multiple state model of Rickayzen & Walsh (2002), which includes disability improvement assumptions over the years in projecting the population with disability levels—from mild to severe—would be effective.

In addition to the above two aspects, Li & Lee (2005) have pointed out the importance of including other countries' demographic rates as a reference for population estimates. There is a strong relationship between developed and developing countries in that the mortality rates and fertility rates of the majority of developed countries are consistently lower to some degree than those of developing countries. The recently developed coherent models, such as the Poisson common factor model (Li 2013) and the product-ratio model (Hyndman et al. 2013), provide a flexible framework to allow the incorporation of two or more sub-populations' demographic rates into the same model. Furthermore, these coherent models maintain a particular structural relationship between the sub-populations and produce non-divergent forecast values between sub-populations in the long run. Such approaches open the possibility of coherently forecasting a developing nation's demographic rates with those of a developed nation, in addition to between males and females and between ethnic groups.

1.2 Contribution of the Study

This thesis is a combination of three substantive chapters, each written in the form of a paper for publication. The overall aim of this thesis is to provide readers with a greater understanding of the changes in the Malaysian population and its demographic components (mortality, fertility and net international migration) over time. In addition, the number of elderly Malaysian according to their disability level is projected. The objective of the thesis is met in the three research papers and the contributions of each paper are outlined below.

1.2.1 Paper 1: Evaluating Extensions to Coherent Mortality Forecasting Models

We evaluate five different mortality forecasting methods in seeking the best model for Malaysia. Accurate mortality forecasts are crucial as mortality is one of the demographic components used for population projections. Although a few papers have treated mortality forecasting for Malaysia (Mohamed et al. 2012, Husin et al. 2015), none of them have included recently developed coherent models to estimate the age-specific mortality rates for the Malaysian sub-populations by gender and ethnic groups.

We employ the two coherent mortality forecasting models, the Poisson common factor (Li 2013) and the product-ratio models (Hyndman et al. 2013) and their associated independent models, the Poisson Lee & Carter (Brouhns et al. 2002) and the functional independent (Hyndman & Ullah 2007), as well as the original Lee

& Carter (1992) model, to forecast Malaysian and Australian age-specific death rates and life expectancy at birth for each sub-population. The coherent models were developed to model the mortality of sub-populations coherently, that is, without having forecast values becoming divergent in the future (Hyndman et al. 2013, Li 2013). Although Hyndman et al. (2013) and Li (2013) were addressing the same issue, several points of difference exist between these two methodologies. Hence, this paper will evaluate the forecast accuracy of both coherent models. The out-of-sample forecast errors of each sub-population of coherent models will be estimated and compared to each other and to their respective independent models and the Lee & Carter (1992) model.

While the literature includes comparisons between both—independent and independent models (Lee & Miller 2001, Booth et al. 2005, 2006, Shang et al. 2011) and independent and coherent models (Hyndman et al. 2013)—no comparisons between coherent models have been made. This research contributes to the mortality forecasting literature by comparing the two coherent models from Li (2013) and Hyndman et al. (2013). Moreover, the application of the Hyndman et al. (2013) and Li (2013) models is extended in this paper to include ethnic coherence in addition to gender coherence. These extensions may be useful for detailed population studies or policy planning for a multi-racial nation like Malaysia.

The main results of this paper showed, in term of overall errors (average between males and females), the gender coherence models are less accurate than their independent models for Malaysia (a high mortality country) but provide more accurate results for Australia (a low mortality country). Nevertheless, further investigation showed that coherent models can be more accurate than the independent models for Malaysia if the fitting period is extended to include more recent trends in which the male and female mortality rates were proportional to each other.

The ethnic coherence models perform better than the independent models for the majority of the Malaysian sub-populations as opposed to the gender coherence models, suggesting the incorporation of lower mortality of the same gendered sub-populations in the coherent model is more accurate than lower mortality of the opposite gendered sub-population.

In this paper we focus only on one demographic component, which is mortality. In the next paper we continue investigating the best forecasting model for other components, such as fertility and net international migration. The forecasts of each of the demographic components will then be used to forecast the age-specific Malaysian population.

The findings of this paper have been presented to the British Society Population Studies Conference, University of Winchester, UK, in September 2014. This paper is currently under review by the Journal of Population Research.

1.2.2 Paper 2: Coherent Stochastic Age-Specific Population Forecasts by Gender and Ethnicity

This paper contributes to the literature by providing comprehensive stochastic population forecasts for Malaysia in which changes in all population components, morality, fertility and net international migration, are accounted for in the projections. We adopt a stochastic method from Hyndman & Booth (2008) so that each of these components can be estimated using the same model. Furthermore, the uncertainties associated with the forecast values can be estimated.

The Hyndman & Booth (2008) paper is extended in three ways. Firstly our research demonstrates that the same product-ratio coherent framework can be successfully applied to all vital rates, that is, we extend this approach beyond mortality and net migration to include fertility. Secondly, we explore another possible type of coherence, developed-developing countries coherence, to forecast each demographic component of a developing country, Malaysia. This type of coherency is used as global mortality and fertility convergence is widely observed (McMichael et al. 2004, Moser et al. 2005). With this method, the application of coherent modelling is extended for the first time to jointly forecast Malaysian vital rates with reference to Australian rates. Thirdly, we use the coherent population forecasting method to forecast the age-specific population by ethnicity.

As mortality forecasting techniques have been described in the first paper, we advance to model Malaysian fertility and net international migration rates in this paper. The age-specific Malaysian population by gender and ethnicity are forecast up to year 2040. Our stochastic Malaysian population forecasts could provide alternative estimates to the deterministic official population projections from the Department of Statistics Malaysia (*DoSM*). In comparison to the *DoSM*, our population forecasts include the uncertainty associated with the forecast values represented by the estimated prediction intervals.

To identify the best population projection method for Malaysia, the Malaysian demographic components are forecast using three different methods—the functional independent model, the gender coherence model, and the developed-developing coherence model. The forecast values of all components are then combined using the cohort-component method to estimate age-specific population forecasts. The out-of sample forecast errors of age-specific death rates, age-specific fertility rates and age-specific population are estimated and compared across methods. The net migration models are excluded from the evaluation as observed Malaysian net migration data are lacking. The number of out migrants has never been published hence the net international migrants data are not available for Malaysia. This paper fills this gap by estimating the observed age-specific net international migration data for Malaysia from 1970 to 2009 using the population growth-balance method (Hyndman & Booth 2008, Rowland 2003).

Our main findings suggest that the developed-developing countries coherence model successfully out-performed the gender coherence model and the independent model for Malaysian males and females. In addition, this model produced the most accurate forecasts for three out of six Malaysian sub-populations by ethnicity and gender—for Chinese males, Chinese females and Malay females. These results indicate that Australian demographic rates can be good reference rates for Malaysia. Nevertheless, careful attention must be given to choosing the fitting period for Australian mortality. The accurate developed-developing countries coherence model is used for long-term population projections for Malaysian males and females. In comparison to the medium variant population projection by the *DoSM*, our mean Malaysian male forecasts are ageing considerably.

1.2.3 Paper 3: Malaysian Long Term Care: Future Demand, costs and effectiveness

In this chapter, we forecast the number of elderly in Malaysia who will require long term care services and their associated costs. While the inadequacy of the current Malaysia public long term care have been extensively discussed and debated in the literature (Ambigga 2011, Ong 2007, Dahlan et al. 2010, Li & Khan 2012), there is a paucity of modelling and estimation of the likely number of elderly demanding public long term care services.

The lack of studies on the demand for Malaysian long term care could well be due to data limitations. Malaysian disability prevalence rates segregated by severity levels have not been published, hence, this chapter fills the gap by providing estimates of the observed and projected age-specific disability prevalence rates by gender and disability levels for Malaysia. The estimation of these rates are based on data from WHS (2002).

The number of disabled elderly Malaysian requiring long term care services were projected using the multiple state model framework from Rickayzen & Walsh (2002). Using this model, mortality and disability improvement were included in the projections. Similar to Leung (2004) and Bueno (2013) we used the reduction factor method from Continuous Mortality Investigation Bureau (1999) in estimating mortality and disability improvement. In addition, we extended the methodology to include another type of mortality improvement—that of developed-developing countries coherence. We use the results from the previous chapter which suggest that Malaysian female and male mortality rates are best forecast using this method.

This chapter proceed to estimate the demand and future costs of Malaysian public long term care programs under the existing policy settings. In order to provide more detailed information about Malaysian long term care, we estimate the cost effectiveness of the current program and compare its effectiveness with Japan.

The findings of this chapter suggest that the population projection method that used the developed-developing countries coherence model to estimate mortality improvement provides slightly higher forecast values compared to the reduction method. We see this when we constrain the disability improvement of both methods to be the same rate, hence the change in population projection is merely affected by the mortality improvement assumptions.

The cost effectiveness measure in term of costs per QALY indicated that low level residential care is effective whereas high level care is not cost effective. While these results must be qualified, they do provide a touchstone for future research.

1.3 Structure of Thesis

The structure of this thesis follows the Thesis by Publication format as recommended by the Higher Degree Research Department, Faculty of Business and Economics, Macquarie University. This first chapter introduced the research. There are three research papers which constitute three chapters to the body of this thesis.

1. Chapter 2 - Shair, Purcal and Parr (2014), “Evaluating Extensions to Coherent Mortality Forecasting Models”.
2. Chapter 3 - Shair, Purcal and Parr (2015), “Coherent Stochastic Age-Specific Population Forecasts by Gender and Ethnicity”.
3. Chapter 4 - Shair and Purcal (2016), “Malaysian Long Term Care: Future Demand, Costs and Effectiveness”.

The final chapter concludes the thesis and emphasises the key findings of each research paper in the thesis. Limitations and recommendations for future research are also outlined in this last chapter.

Chapter 2

Paper 1

Evaluating Extensions to Coherent Mortality Forecasting Models

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Abstract

Coherent models were developed recently to forecast the mortality of two or more sub-populations simultaneously and to ensure long term non-divergent mortality forecasts of sub-populations. This paper evaluates the forecast accuracy of two recently published coherent mortality models—Poisson common factor and product-ratio functional. These models are compared to each other and to their corresponding independent models, and to the original Lee & Carter model. All models are applied to age-sex specific mortality data for Australia and Malaysia and age-sex-ethnicity specific data for Malaysia. The out-of-sample forecasts error of log death rates, male to female death rate ratios and life expectancy at birth for each model are compared and examined across groups. The results show that, in terms of overall accuracy, the forecasts of both coherent models are consistently more accurate than those of the independent models for Australia and for

Malaysia but the relative performance differs by forecast horizon. Although the product-ratio functional model outperforms the Poisson common factor model for Australia, the Poisson common factor is more accurate for Malaysia. For the ethnic groups application, ethnic-coherence gives better results than gender-coherence. The results provide evidence that coherent models are preferable to independent models for forecasting sub-populations' mortality.

Keywords: Coherent Mortality Forecasting Models; Lee & Carter model; Mortality Forecasting Accuracy; functional data model

2.1 Introduction

Mortality and population estimates are becoming increasingly important for planning purposes, in particular, to ensure that social services and financial assistance can support the needs of the elderly (Woods & Dunstan 2014).

Initially, mortality models tended to rely on subjective opinions of experts about future trends (Pollard 1995). This bias in forecast results was eventually reduced by extrapolative methods that make use of past data and assume that a common historical pattern will continue in the future. Lee & Carter (1992) is a significant extrapolative model that accounts for population ageing in forecasting mortality rates. The Lee & Carter model out-performed forecasts of US Social Security and was deemed reliable for US mortality data. However, despite its success in the US, Lee & Carter's model assumptions were invalid in some countries (Booth et al. 2002) and therefore needed further modifications. A number of modifications have been implemented in the last two decades. Specifically, the Lee & Carter model was adjusted to be more flexible with the addition of a variant age-component assumption (Lee & Miller 2001, Booth et al. 2002), and more reliable with a linear decreasing time-component assumption made (Tuljapurkar et al. 2000, Booth et al. 2002, Li 2010, Hyndman et al. 2013). In addition, Lee & Carter methods were extended from a non-parametric model to a parametric model that applies a Poisson distribution function to estimate deaths (Brouhns et al. 2002, Renshaw & Haberman 2003). Another improvement to the model included the use of a functional data approach to smooth the observed rates which allowed for five-year-age interval forecasts (Hyndman & Ullah 2007). It is noteworthy that the mortality forecasts of the modified Lee & Carter model have proven to be more accurate than those of the original (Booth et al. 2005, 2006, Shang et al. 2011)

The Lee & Carter model and its extensions are classified as an independent model—a model that works well for single or combined population forecasts (Li & Lee 2005). However, one of the disadvantages of independent forecasting is that this model forecasts sub-populations (such as males and females) separately and it fails to account for the relationship between groups Li (2013). Another problem with this approach is that it produces divergent forecasts between two or more sub-populations which may poorly represent the smaller populations within the same larger region or country (Hyndman et al. 2013). These limitations suggest that independent models may be inappropriate for multiple sub-population forecasting.

In order to address the limitations of independent models, coherent models were proposed. Coherent models are designed to forecast the mortality of two or more sub-populations simultaneously and to ensure that the forecasts of these sub-populations reflect connection with each other. One of the first coherent models was the augmented common factor model developed by Li & Lee (2005) which extends Lee & Carter model in two ways. First, the model incorporates the mortality reference (the aggregated death rates of sub populations) in the base model to maintain the historic relationship between groups. Second, the model restricted the sub populations' time-component to $AR\ (1)$ forecasts which guarantees non-divergent forecasts in the long run. This technique improved on the divergent forecasts of the independent models over a variety of metrics. Consequently, new coherent models have recently been developed. These include the Poisson common factor model of Li (2013) and the product ratio functional model of Hyndman et al. (2013). The details for both these coherent models' methodologies are explained in section 2.

The comparison of mortality forecasting models (independent or coherent) is vital for identifying which of the models could provide more accurate forecasts. While the literature includes comparisons between both—independent and independent models (Lee & Miller 2001, Booth et al. 2005, 2006, Shang et al. 2011) and independent and coherent models (Hyndman et al. 2013), no comparisons between coherent models have been made. Another gap in the literature is that, the applications of coherent forecasting models have only been conducted using data from developed countries ; and coherent models have not been tested in less developed countries where mortality trends are different.

The purpose of this research is to evaluate the forecast accuracy of two recent coherent models: Poisson common factor model and product ratio functional model. The two coherent models will be compared to each other and to their respective independent versions: the Poisson Lee & Carter model and the weighted functional model. In addition, because all four models are the extensions of the Lee & Carter model, we include Lee & Carter forecasts as a performance benchmark. We extend the application of coherent mortality forecasting to include less developed nation, Malaysia, as well as Australia. In applying the coherent models, we use gender-coherence for Malaysian and Australian age-gender-specific mortality data. Furthermore, we apply two types of coherency: gender-coherence and ethnic-coherence on Malaysian age-gender-ethnic-specific mortality data. We forecast death rates, male to female death rate ratios and life expectancy at birth and compare the out-of-sample forecast with the observations from the official statistics.

This paper is organised as follows: Section 2.2 explains the coherent models (Poisson common factor and product ratio functional models) and describes the error measures that we use to estimate the out-of-sample forecast errors. Section 2.3 discusses the observed mortality rates and their trend in Australia and Malaysia. In section 2.4 and 2.5, we apply sex-specific data for Australia and Malaysia and ethnic-specific mortality data for Malaysia to the coherent and independent models and report the forecast accuracy of death rates, male to female sex ratios and life expectancy at birth. Finally, section 2.6 provides discussion and a conclusion.

2.2 Coherent mortality forecasting

2.2.1 Poisson common factor model

The Poisson common factor model based on the Poison parametric distribution function was developed by Li (2013) to estimate number of deaths directly. The method extends an independent model, Poisson Lee & Carter from Brouhns et al. (2002). The model formulation is as below.

$$\log(m_{x,t,i}) = a_{x,i} + \beta_x K_t + \sum_{j=1}^{J} b_{x,i,j} k_{t,i,j} + \epsilon_{x,i,t} \tag{2.1}$$

In equation (2.1), $m_{x,t,i}$ is the age-specific death rate in year t for the i^{th} sub population. $a_{x,i}$ is the average of the log age-specific death rates for a i^{th} group over the years. $\beta_x K_t$ is the product of an age-component and time-component for the common factor and $b_{x,i,j}k_{t,i,j}$ is the product of an age-component and a time-component for i^{th} sex-specific factor which include more than one additional factors j^{th} in the model. $\epsilon_{x,i,t}$ is the residual at age x and year t.

The equation (2.1) is identical to its independent version, Poisson Lee & Carter model (Brouhns et al. 2002), if the value of $\beta_x K_t$ is zero and just one sex-specific factor is being considered. Clearly, without common factor variables, the model does not account for inter-relationship between sub-populations.

In deriving parameters, Poisson common factor model adopted similar technique to its independent version using maximum log-likelihood function as follows

$$D_{x,t,i} = Poisson(E_{x,t,i}, m_{x,t,i}) \tag{2.2}$$

with

$$m_{x,t,i} = \exp(a_{x,i} + \beta_x K_t + \sum_{j=1}^{J} b_{x,i,j}k_{t,i,j}) \tag{2.3}$$

Deaths $D_{x,t,i}$ are modelled directly from Poisson distribution function for i^{th} population with $E_{x,t,i}$ is its respective exposure. The age-specific mortality rates, $m_{x,t,i}$ are considered as unknown values and are estimated using (2.3) subject to the constraint $\sum_t K_t = 0$, $\sum_x \beta_x = 1$ and $2IJ$ constraint of $\sum_t k_{t,i,j} = 0$ and $\sum_x b_{x,i,j} = 1$ where the number of factors I and J can be optimally determined using either Bayesian Information Criterion (BIC) or the Akaike Information Criterion (AIC).

Following Brouhns et al. (2002), parameters $a_{x,i}$, β_x, K_t, $b_{x,i,j}$ and $k_{t,i,j}$ are estimated via iterative updating scheme which is explained in a systematic way in Li (2013). The time-component of common factor is a non-stationary, a random walk with drift is used to forecast the data. The sex-specific time-components on the other hand are stationary hence a p^{th} order autoregressive model $AR(p)$ is used. Finally, age-specific death rate forecasts can be retrieved by placing the forecasted time-components and estimated age factors in the equation (2.3).

2.2.2 Product-ratio functional model

Hyndman et al. (2013) extended the Hyndman & Ullah (2007) independent method, functional time series model to model the two quantities known respectively as the product $p_{x,t}$ and the ratio $r_{x,t,i}$ functions. The product and ratio functions are defined below

$$p_{x,t} = \left[\prod_{i=1}^{I} f_{x,t,i}\right]^{\frac{1}{I}} \tag{2.4}$$

$$r_{x,t,i} = \frac{f_{x,t,i}}{p_{x,t}} \tag{2.5}$$

Where $i = 1, 2 \ldots I$ are the number of sub-populations and $f_{t,i,x}$ the smoothed age-specific mortality rates for the i^{th} population. For a smoothing procedure, Hyndman et al. (2013) use weighted penalized regression splines. A monotonic increasing constraint over time is imposed on age x and above. The product function $p_{t,x}$ is estimated as the geometric mean of the smoothed rates of sub populations which represents the general trend or mortality reference of sub-populations. $r_{t,i,x}$ is the ratio of one sub population's rates to the geometric mean and this represent the mortality difference of a particular sub-population to the general trend.

The product and ratio function have the advantage of being easy to use and are uncorrelated with each other on the log scale. Both are then applied to the functional time series model (Hyndman & Ullah 2007) as below,

$$\log p_{x,t} = ap_x + \sum_{l}^{L} \beta_{x,l} K_{t,l} + ep_{x,t}, \tag{2.6}$$

$$\log r_{x,t,i} = ar_{x,i} + \sum_{j}^{J} b_{x,i,j} k_{t,i,j} + er_{x,t,i}, \tag{2.7}$$

where ap_x and $ar_{x,i}$ are the averages of the logs of the product and ratio functions respectively. The time component $K_{t,l}$ and the $k_{t,i,j}$ and the age component $\beta_{x,l}$ and $b_{x,i,j}$ are estimated using a weighted principal component analysis from Shang et al. (2011) which applies more weight to recent data. The weighting technique is used to cater for change over time in $\beta_{x,l}$ and $b_{x,i,j}$. In contrast to Li & Lee (2005), who used only the first principal component, Hyndman et al. (2013)

used up to six components. The time-component for the product function $K_{t,l}$ displays a linear decreasing trend and therefore is more appropriately forecast using a non stationary series model, $ARIMA(p,d,q)$. A non-divergent mortality forecast is attained when $k_{t,i,j}$ is restricted to forecast using a stationary time series model either an autoregressive moving average $ARMA(p)$ or an auto-regressive fractional integrated moving average $ARFIMA(p,d,q)$.

The estimated average death rates and age factors as well as the forecast time components are put into equations (2.6) and (2.7) to get the forecast values of the product and ratio functions. Subsequently, the age-specific mortality forecasts for each sub population are obtained by simply multiplying the forecast rates of the product and ratio as follows

$$\log f_{x,t,i} = \log[p_{x,t} r_{x,t,i}] = a_{x,i} + \sum_{l}^{L} \beta_{x,l} K_{t,l} + \sum_{j}^{J} b_{x,i,j} k_{t,i,j} + e_{x,t,i} \tag{2.8}$$

Where $a_{x,i} = ap_x + ar_{x,i}$ and $e_{x,t,i} = ep_{x,t} + er_{x,t,i}$ are the mortality average and error term respectively for a particular group. Equation (2.8) is similar to that of Li (2013) given in (2.1), when there is no additional component for $\beta_x K_t$. The product-ratio functional and its independent model can be implemented using the 'demography' package in R (Hyndman 2013).

2.2.3 The forecast accuracy measurement

We divide t-year observations of a particular i^{th} sub population into two parts. First, the in-sample data which consists of the first n-year observations, $y_{x,i,1}$, $y_{x,i,2}$, …, $y_{x,i,n}$ and are fitted into each model to estimate parameters. Second, the out-of-sample data, comprising the remaining $t-n$ years of data $\{y_{x,i,n+1}, y_{x,i,n+2}, \dots, y_{x,i,n+t}\}$ which are compared to the forecast rates $\{F_{x,i,n+1}, F_{x,i,n+2}, \dots, F_{x,i,n+t}\}$.

From the out-of-sample data, the forecast accuracy of each model is estimated using the following error measurements

$$MAFE_i = \frac{\sum_{j=1}^{t} \sum_{x=1}^{p} \left| y_{x,i,n+j} - F_{x,i,n+j|n} \right|}{pt}, \tag{2.9}$$

$$MFE_i = \frac{\sum_{j=1}^{t}\sum_{x=1}^{p}\left(y_{x,i,n+j} - F_{x,i,n+j|n}\right)}{pt}, \tag{2.10}$$

$$MAPFE_i = \frac{\sum_{j=1}^{t}\sum_{x=1}^{p}\left|\frac{y_{x,i,n+t} - F_{x,i,n+j|n}}{y_{x,i,n+j}}\right| \times 100}{pt}. \tag{2.11}$$

We use mean absolute forecast error ($MAFE_i$) and mean forecast error (MFE_i) to evaluate the forecast accuracy of the log death rates and life expectancy for i^{th} sub-population. For male to female death rate forecasts, errors are estimated using $MAPFE_i$.

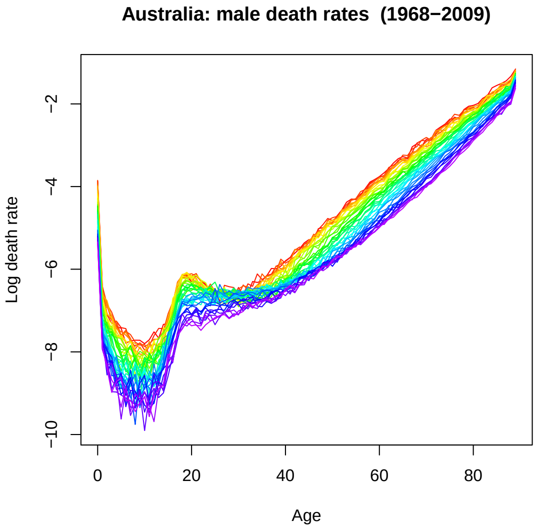
2.3 Mortality data

In this study, we use central age-sex-specific death rates for Australia and Malaysia and age-sex-ethnic-specific death rates for Malaysia as well as their respective mid-year exposures. The data for Australia are taken from the Human Mortality Database (2014) from 1921 to 2009 for ages 0 to 110. Malaysian data from the Malaysian Department of Statistics are available from 1965 to 2011 for ages 0 to 80. The mortality rates for the oldest ages fluctuate widely. Therefore, following Li (2013), we exclude some of the oldest rates and include only data up to 90 years old for Australia.

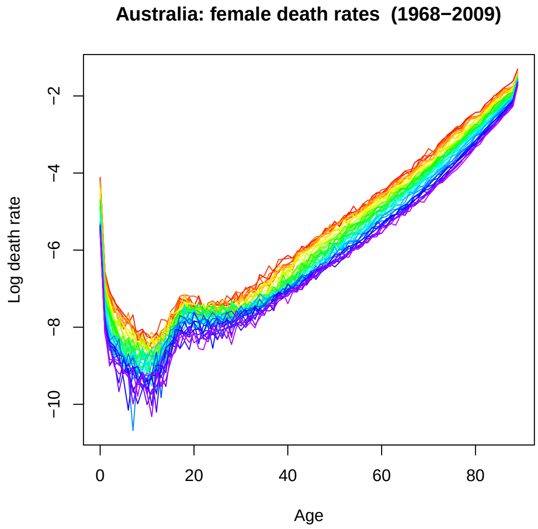
In order to improve the forecast accuracy, an appropriate starting year for the fitting period must be selected for the extension versions of the Lee & Carter, to ensure mortality index is reasonably linearly decreasing. For the original Lee & Carter model, the starting year for the fitting period is the earliest available year (1921 for Australia and 1965 for Malaysia), regardless of whether or not the mortality index has been subject to change over time. From Figure 2.1, major shifts in the mortality index of the Lee & Carter model can be seen clearly in late 1960s for Australia and in the early 1970s and late 1990s for Malaysia.

Booth et al. (2002) suggested that 1968 and 1970 are the best starting year for the fitting period for Australia males and females whereas Hyndman et al. (2013) used 1950 to fit the age-region-specific death rates to the product-ratio functional model. In this study, for comparative purposes, all models except for the original Lee & Carter model will use the same starting years namely 1968 for Australia and 1975 for Malaysia. The selection of these starting year is based

Figure 2.1: Mortality index or time component, K_t, estimated from the Lee & Carter model for the Australian total population from 1921 to 2009 (left) and for the Malaysian total population from 1965 to 2011 (right).



(a)



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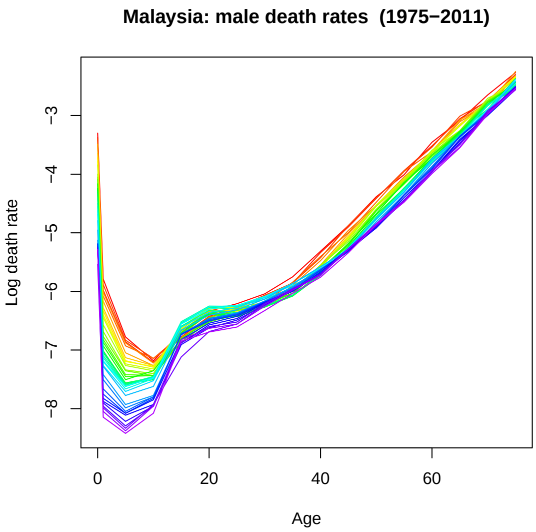

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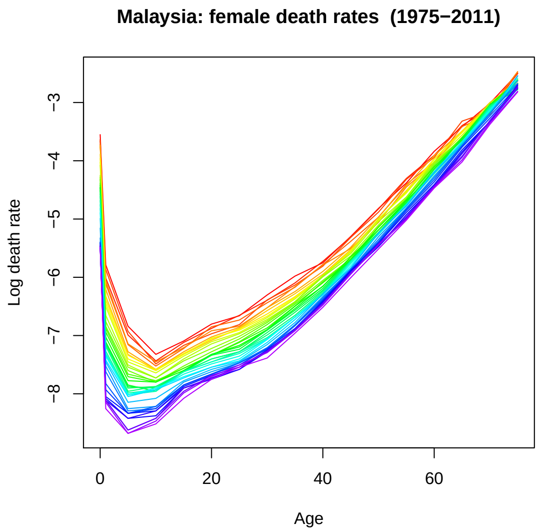


(d)

Figure 2.2: The rainbow age-specific log death rate plots for females (right) and males (left) for Australian (above) and Malaysian (below). The first few years are shown in red, followed by orange, yellow, green, blue and indigo with the last few years plotted in violet.

on the observation of the mortality index patterns over time in both countries. From Figure2.1, a more linearly decreasing pattern with a profound change in the mortality index structure can be seen approximately after 1968 for Australia and 1975 for Malaysia.

The log age-specific death rates plots for males and females are as shown in the Figure 2.2. The top panel is Australian death rates which clearly exhibit similar pattern between males and females. The decreasing rates over the years from red to purple (1968–2009) occur in all ages. However, mortality is decreasing at a slower rate in recent years than in previous years. This as shown by a small decrease from blue to purple (1990–2009) curves. The male accident hump decreases more rapidly than female in recent years. According to Pollard (1996), the disappearance of the accident lump among young males aged 14 to 24 and early adult ages 25 to 40 since the late 1980s is due to a declining rate of motor accident fatalities from 1982, a results of the introduction of random breath testing of drinker for alcohol and seat-belt regulation.

The bottom panel displays inconsistent pattern between Malaysian female and male mortality especially for the accident hump ages. Female mortality has declined consistently over the years (1975–2011) in all age groups with a thin accident hump can be seen in recent years. Mortality of males for accident hump (aged 15 to 39) fluctuate in early years (1975–1997). However a decreasing pattern can be seen in the later years starting from 1998. The inconsistent pattern of change over time between the genders leads to the highest ratio of male to female death rates in this age group from 1975 to 1997 (Mohamed et al. 2012).

2.4 Application to Australian and Malaysian mortality

Our forecasts are based on five different mortality forecasting models which include two coherent models, the Poisson common factor and the product ratio functional models, and their independent versions, the Poisson Lee-Carter and the weighted functional models. These four models are the extensions of the Lee & Carter (1992) model hence the original model is included as the performance benchmark.

This section reports the forecast error of log age-sex-specific death rates, male

Table 2.1: Mean Absolute Forecast Error (*MAFE*) of log death rates for males and females by method, sex and country.

	$MAFE^1$					
	Australia			Malaysia		
	Male	Female	Overall	Male	Female	Overall
20-year forecasts						
Poisson Lee & Carter	0.184	0.162	0.173	0.118	0.100	0.109
Poisson common factor	0.175	0.156	0.166	0.152	0.089	0.120
Weighted functional	0.171	0.135	0.153	0.123	0.111	0.117
Product-ratio functional	0.163	0.134	0.149	0.170	0.077	0.124
Lee & Carter	0.472	0.333	0.402	0.150	0.179	0.164

to female death rate ratios and life expectancy at births for five different mortality forecasting methods (coherent and independent) in Australia and Malaysia.

2.4.1 Log death rate forecast

Table 2.1 presents the mean absolute forecast errors of log death rates for different methods averaged over age and year for male and female mortality rates in Australia and Malaysia. In comparison to the independent models, both coherent models are more accurate for three out of four sub-populations: Australian males and females and Malaysian females, while the independent models perform better than the coherent models for Malaysian males. In term of the overall accuracy (averaged over male and female errors), the coherent models perform better than the independent models for Australia but underperform for Malaysia. The product ratio functional model (coherent) performs the best for Australia, while the Poisson Lee & Carter model (independent) performs the best for Malaysia.

Between the two coherent methods, the product ratio functional model is more accurate than its counterpart Poisson Common factor and proved to be the best model for the three out of four sub-populations: Australian males and females and Malaysian females. When taking the average over genders the product ratio functional model performs better than the Poisson common factor model for Australia but less well than it for Malaysia. Among the five models, all Lee & Carter extensions perform significantly better than the original model for both genders in Australia and for females in Malaysia. It is noteworthy that for Malaysian male mortality, the Lee & Carter model is more accurate than coherent models but under performs the other independent models.

Table 2.2: Mean Forecast Error (*MFE*) of log death rates for males and females by method, sex and country.

	MFE[1]					
	Australia			Malaysia		
	Male	Female	Overall	Male	Female	Overall
20-year forecasts						
Poisson Lee & Carter	-0.094	-0.024	-0.059	0.072	0.060	0.066
Poisson common factor	-0.087	-0.031	-0.059	0.120	0.006	0.063
Weighted functional	-0.094	-0.036	-0.065	0.087	0.094	0.090
Product-ratio functional	-0.070	-0.030	-0.050	0.157	0.039	0.098
Lee & Carter	0.148	0.142	0.145	0.102	0.122	0.112

Table 2.2 summarises the corresponding mean forecast errors[1]. The Lee & Carter model overestimates Australian male and female mortality rates substantially in contrast to the other four models. For Malaysia, all models consistently overestimate both genders' mortality with the Lee & Carter model being the least accurate model for Malaysian females. Consistent with Table 2.1, in term of overall accuracy, the product ratio functional model is the most accurate for Australia while the Poisson Lee & Carter is the most accurate for Malaysia.

Figure 2.3 shows the mean forecast errors by age. Clearly, the original Lee & Carter model provides significant errors for Australia and underestimates the mortality for people under 40 and overestimates the mortality of those who are aged above 40. However, for Malaysia, Lee & Carter forecasts are fairly similar to the other four methods especially for males. The errors for the coherent (dashed lines) and the independent (solid lines) models are generally similar in pattern for both countries. As can be seen from Figure 2.3, there is an extreme point of error for the Poisson-based methods around age 12 for both genders in Australia. However, no outlier is detected for the functional-based methods, which indicates the ability of the functional models to minimize the effect of extreme forecast values.

2.4.2 Male to female death rate ratio forecast

The forecast error of male to female death rate ratios is presented in Table 2.3. The overall error shows that coherent models are more accurate than independent models for Australia but less accurate for Malaysia. Table 3 shows substantial

[1]Mean over age groups and years. overall refers to average of male and female errors

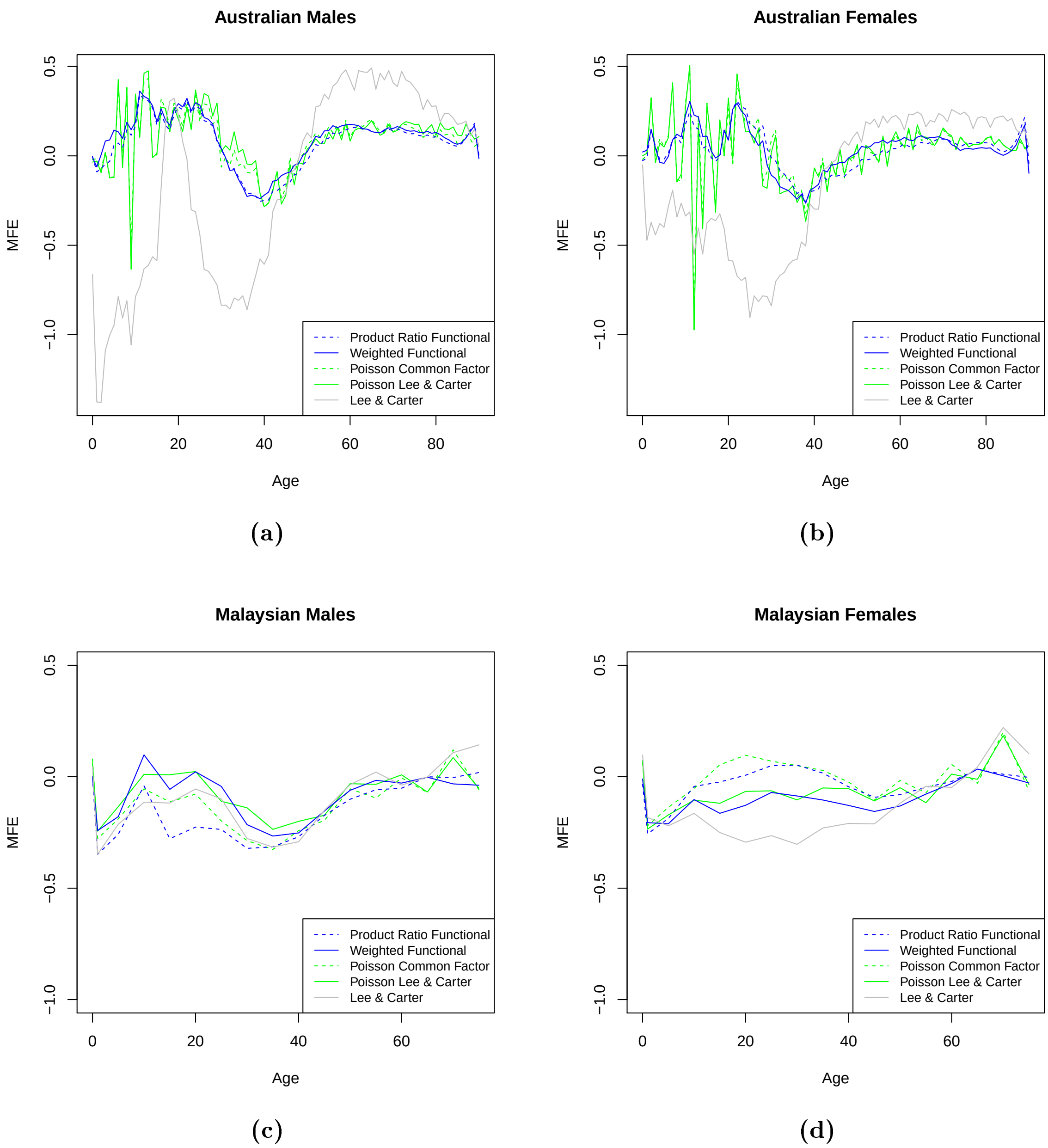


Figure 2.3: Mean Forecast Error (*MFE*) by age and methods for Australia (top panel) and Malaysia (bottom panel).

errors at younger ages (1 to 39) for all methods in both countries. This indicates the difficulty in estimating the childhood mortality and the accident hump. Shang et al. (2011) concluded the same for the log death rates forecast over the 14 countries.

As for Australia, the coherent models have lower forecast errors than the independent models for the infant, children, young adult and the oldest old groups. Although coherent models have higher errors than the independent models for the Australian middle-age and old groups, the difference insignificant and the coherent models perform better than the independent models in overall terms. For Malaysia, the coherent models have lower forecast errors than the independent models for the infant, child, old and oldest old groups and significantly higher errors for the young adult and middle-age groups. For example, the errors of the young adult group increase from 14.67 to 22.32 (by 52%) for Poisson common factor model and from 16.91 to 24.92 (by 54%) for product ratio functional model. The high percentage error from this Malaysian young adult group causes the coherent models to perform less accurately than the independent models.

The comparisons between the two coherent models show that the product ratio functional model is consistently more accurate than the Poisson common factor for all age groups in Australia and for the age group 40 and above in Malaysia. Similar to results reported in Table 2.1, the overall errors show that the product ratio functional model (a coherent model) is the best model for Australia while Poisson Lee & Carter (an independent model) is the best model for Malaysia.

Figures 2.4 and 2.5 present the forecast of male to female death rate ratios for Australia and Malaysia. As can be seen from both Figures 2.4 and 2.5, the coherent models (left panel) produce constant forecast ratios for all ages in contrast to the diverging rates under the independent models (right panel) especially for the 15 to 39 age groups.

2.4.3 Life expectancy at birth forecast

Next, we evaluate each model's accuracy using life expectancy at birth as the outcome measure. The overall errors in Table 2.4 appear to be consistent with the log death rates and male to female death rate ratios forecast errors in two ways. Firstly, the coherent models are more accurate than the independent models for Australia but are less accurate for Malaysia. Secondly, the errors from the Lee

Table 2.3: Mean Absolute Percentage Forecast Error (*MAPFE*) of male to female death rate ratios by age, method and country.

	Australia *MAPFE*[1]						
	0 infant	1–14 child	15–39 young adult	40–54 middle-age	55–69 old	70–90 oldest old	Overall
20-year forecast							
Poisson Lee & Carter	4.60	62.07	30.21	11.64	9.41	8.90	21.14
Poisson common factor	3.74	55.31	23.15	11.65	11.46	6.21	18.59
Weighted functional	4.40	31.24	18.94	8.05	7.96	8.16	13.13
Product-ratio functional	3.67	30.36	15.93	8.46	10.00	5.13	12.26
Lee & Carter	45.78	41.39	45.23	14.45	26.22	10.89	30.66
	Malaysia *MAPFE*[1]						
	0 infant	1–14 child	15–39 young adult	40–54 middle-age	55–69 old	70–90 oldest old	Overall
20-year forecast							
Poisson Lee & Carter	3.24	8.35	14.67	7.67	5.20	6.20	7.55
Poisson common factor	2.28	4.71	22.32	10.61	4.32	5.32	8.26
Weighted functional	2.25	12.32	16.19	7.28	3.99	4.36	7.73
Product-ratio functional	3.71	6.35	24.98	10.58	3.25	4.14	8.84
Lee & Carter	6.79	10.18	18.70	7.66	4.20	7.54	9.18

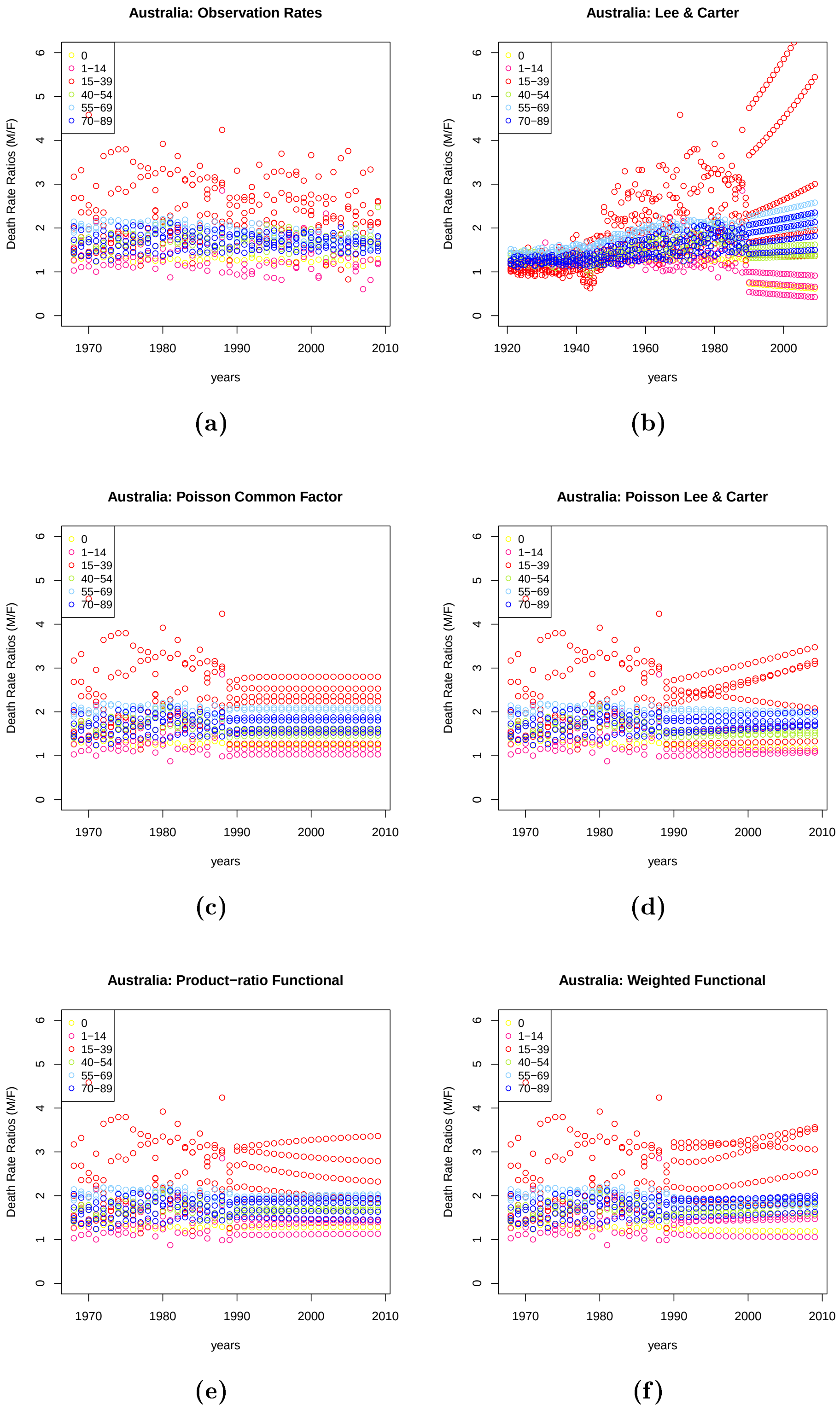


Figure 2.4: Australian observed and forecast male to female death rate ratios from 1968 to 2009.

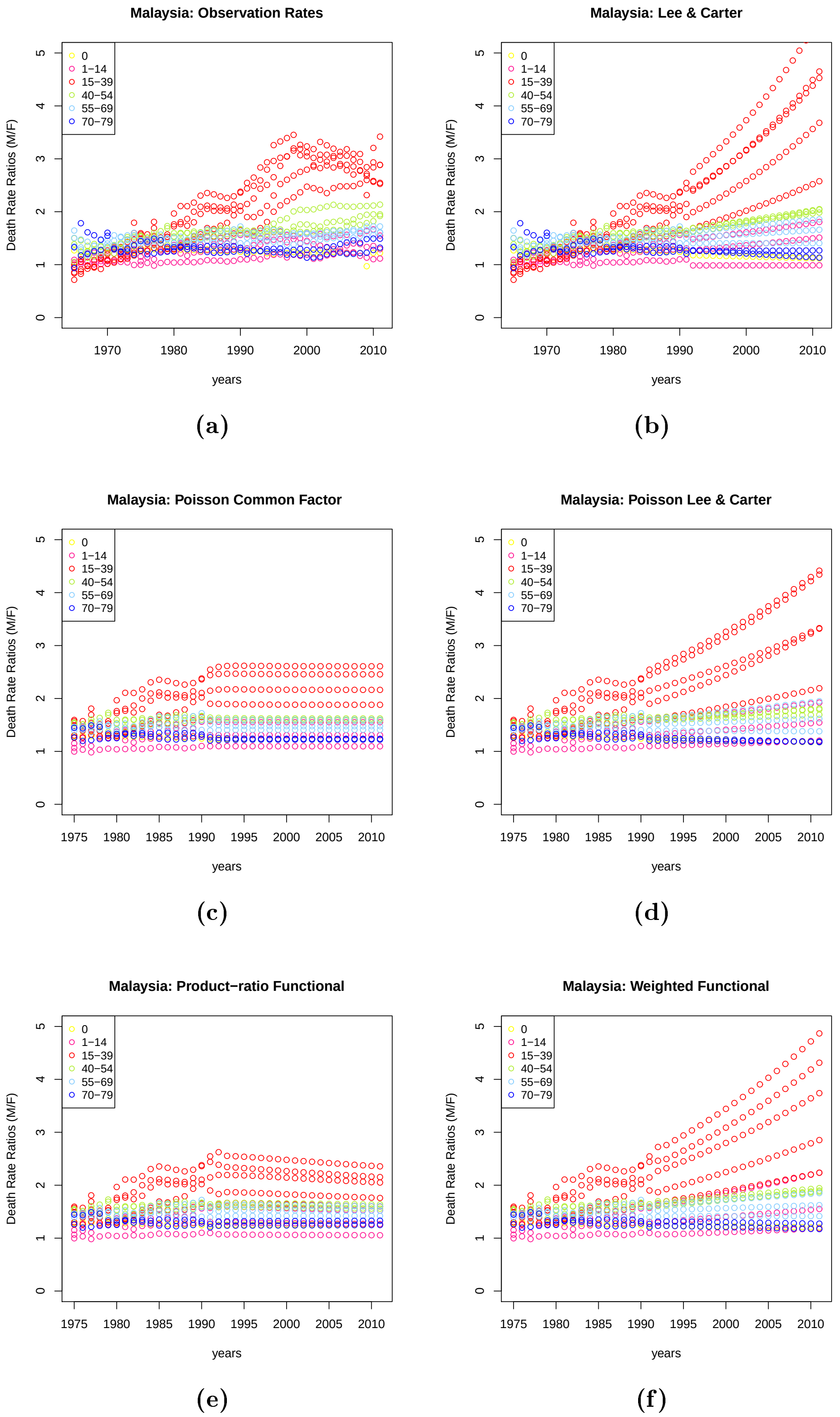


Figure 2.5: Malaysian observed and forecast male to female death rate ratios from 1975 to 2011.

& Carter extensions are reasonably similar. However the error from the original Lee & Carter model is significantly higher for Australia.

From Table 2.5, all models underestimate life expectancy at birth for both Australian males and females, with the forecast errors among males being more than twofold greater than among females. In other words, the methods used in this research tend to underestimate the rapid increase in life expectancy for Australian males which has occurred in recent years. In contrast, all the models overestimate the life expectancy for Malaysian males, with the original Lee & Carter model providing the least error. The result for Malaysian females are less consistent.

As can be seen from Tables 2.4 and 2.5, the Lee & Carter model is the most accurate model for Malaysian males. This suggests that in some cases, such as in a developing country like Malaysia, where the available observed data is not extensive (available only since 1965), the original Lee & Carter model may still be reliable. In addition, consistent with Booth et al. (2006), results provide further empirical evidence that the most accurate model for mortality rates is not essentially the best model for life expectancy.

Figure 2.6 shows that the Lee & Carter model significantly underestimates the life expectancy at birth for both genders in Australia. Conversely, this model outperforms the other models for Malaysian males. The significant underestimation of Lee & Carter model for Australian life expectancy maybe due to the fact that this model includes structural changes in time-component that have happened since 1921. For Malaysia, there was no major structural change in the data after 1965, hence the Lee & Carter model performs at least as well as the other methods. Furthermore, the coherent forecasts (dashed lines) display proportional rates between males and females whereas the independent forecasts (solid lines) tend to diverge and generally produce a bigger gap between the genders.

2.4.4 The potential of coherent mortality forecasting for future in Malaysia

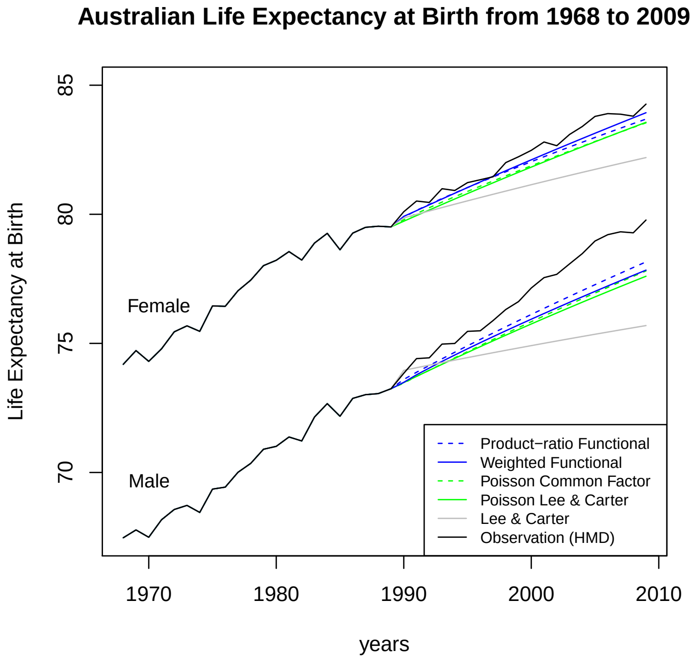
From 1998 onwards (turquoise to purple curves from the Figure 2.2), Malaysian male mortality for the accident hump group no longer fluctuates but rather it decreases consistently over the years. This observation raises the question of whether this trend will continue in the future and increases the chance of the

Table 2.4: Mean Absolute Forecast Error (*MAFE*) of life expectancy at birth by method, sex and country.

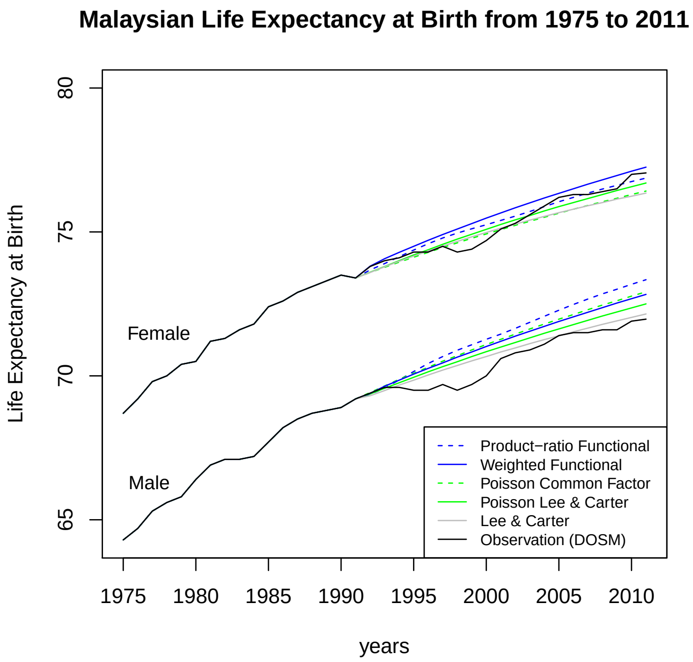
	$MAFE^1$					
	Australia			Malaysia		
	Male	Female	Overall	Male	Female	Overall
20-year forecasts						
Poisson Lee & Carter	1.289	0.567	0.928	0.466	0.213	0.339
Poisson common factor	1.202	0.521	0.861	0.724	0.295	0.509
Weighted functional	1.123	0.290	0.706	0.660	0.371	0.516
Product-ratio functional	0.945	0.355	0.650	0.945	0.223	0.584
Lee & Carter	2.044	1.201	1.622	0.289	0.302	0.296

Table 2.5: Mean Forecast Error (*MFE*) of life expectancy at birth by method, sex and country.

	MFE^1					
	Australia			Malaysia		
	Male	Female	Overall	Male	Female	Overall
20-year forecasts						
Poisson Lee & Carter	-1.289	-0.567	-0.928	0.460	-0.035	0.213
Poisson common factor	-1.202	-0.521	-0.861	0.724	-0.203	0.261
Weighted functional	-1.123	-0.290	-0.706	0.660	0.372	0.516
Product-ratio functional	-0.945	-0.335	-0.650	0.938	0.131	0.534
Lee & Carter	-2.044	-1.201	-1.622	0.269	-0.187	0.041



(a)



(b)

Figure 2.6: Observed and 20-year forecasts of Australia (top) and Malaysia (bottom) life expectancies at birth for males and females.

Table 2.6: Mean Absolute Forecast Error (*MAFE*) and Mean Forecast Error (*MFE*) of log death rates for males and females by method and sex for Malaysia.

	$MAFE^1$					
	MAFE			*MFE*		
	Male	Female	Overall	Male	Female	Overall
10-year forecasts						
Poisson Lee & Carter	0.072	0.082	0.077	-0.017	0.030	0.007
Poisson common factor	0.059	0.059	0.059	0.022	-0.002	0.010
Weighted functional	0.111	0.076	0.093	-0.049	0.012	-0.018
Product-ratio functional	0.071	0.060	0.065	0.024	-0.007	0.009
Lee & Carter	0.100	0.161	0.130	0.019	0.109	0.0.064

coherent models outperforming the independent models. For this section we extend the fitting period for Malaysia data to include the recent decreasing trend among males. About two thirds of the observations (i.e., from 1975 to 2001) are used for the estimation, and the remaining ten years (from 2002 to 2011) are left for the evaluation of forecasts. Tables 2.6, 2.7 and 2.8 present the 10-year forecast errors of mortality rates, male to female death rates and life expectancy at birth.

Interestingly, the results show that when a longer estimation period is used, the coherent models are more accurate than the independent models for both Malaysian genders and give similar results to the Australia 20-year forecasts. The error from independent models for people aged 15 to 39 is reduced substantially from 22.564 to 5.491 or by 76% and from 23.367 to 6.743 or by 71% (Table 7). These results confirm that the improvement in male mortality rates for people aged 15 to 39 plays an important role for the accuracy of coherent forecasts and consequently outperforms independent models. Nevertheless, the life expectancy forecasts show that the coherent models are still under performing the independent models for Malaysia.

Table 2.7: Mean Absolute Percentage Forecast Error (*MAPFE*) of male to female death rate ratios by age and method for Malaysia.

	Malaysia *MAPFE*[1]						
	0 infant	1–14 children	15–39 young adult	40–54 middle-age	55–69 old	70–90 oldest old	Overall
10-year forecast							
Poisson Lee & Carter	4.228	7.158	22.564	5.291	2.928	9.599	8.628
Poisson common factor	3.622	4.572	5.491	5.565	3.209	6.700	4.860
Weighted functional	17.614	15.948	23.367	4.108	2.754	8.973	12.127
Product-ratio functional	3.502	4.121	6.743	6.762	4.683	6.646	5.409
Lee & Carter	5.231	11.907	35.384	3.070	4.483	8.778	11.475

Table 2.8: Mean Absolute Forecast Error (*MAFE*) and Mean Forecast Error (*MFE*)of life expectancy at birth for males and females by method and sex for gender.

	MAFE[1]			*MFE*[1]		
	Male	Female	Overall	Male	Female	Overall
10-year forecasts						
Poisson Lee & Carter	0.092	0.315	0.203	-0.073	-0.315	-0.194
Poisson common factor	0.191	0.272	0.232	0.183	-0.268	-0.043
Weighted functional	0.190	0.320	0.255	-0.188	-0.320	-0.254
Product-ratio functional	0.238	0.341	0.290	0.237	-0.342	-0.053
Lee & Carter	0.076	0.268	0.172	0.029	-0.246	-0.109

2.5 Application to Malaysian ethnic group mortality

Malaysia is a multicultural country which consists of three main ethnic groups: Malay and Indigenous groups, Chinese and Indian. Chinese mortality is consistently lower than the Malays and Indians for both genders. This leads to Chinese has the highest life expectancy at birth (Figure 2.7). In view of the diversity of Malaysian population, we investigate the suitability of the coherent models to forecast the mortality rates of these ethnic groups. Gender-coherence is applied separately on Malay males and females, Chinese males and females, and Indian males and females. Meanwhile ethnic-coherence is applied on Malay, Chinese and Indian males and Malay, Chinese and Indian females. We report the impact of applying different type of coherence in this section.

2.5.1 Gender-coherence

Table 2.9 presents the log death rates forecast error of different methods. We exclude the Lee & Carter model for this application. The patterns of error of the Malay and indigenous population forecasts are consistent with those of the national forecast: both coherent models are more accurate than independent models for females but less accurate for males, leading to the coherent forecasts having less accuracy than the independent forecasts overall. This may be due to Malay being the majority of the Malaysian population. For Indian, the coherent models are less accurate than the independent models for both males and females. For the Chinese, the forecasts generate results that are different from national forecasts but similar in patterns of error to those of a low mortality country, Australia, for which both the coherent models are more accurate than the independent models for the overall forecasts. The comparison between the two coherent models for Chinese indicates that the Poisson Common factor model outperforms the product ratio functional model in the overall forecasts.

The results for male to female death rate ratios tend to be consistent with the log death rates forecasts in term of overall accuracy: the coherent models are less accurate than the independent for Malay and Indian but are more accurate than the independent for Chinese. However, the life expectancy at birth forecasts show that the coherent models are less accurate than the independent models for all

Table 2.9: Mean Absolute Forecast Errors (*MAFE*) according to ethnic groups and sex in Malaysia. Gender-coherence imposed on coherent models for Malay, Chinese and Indian.

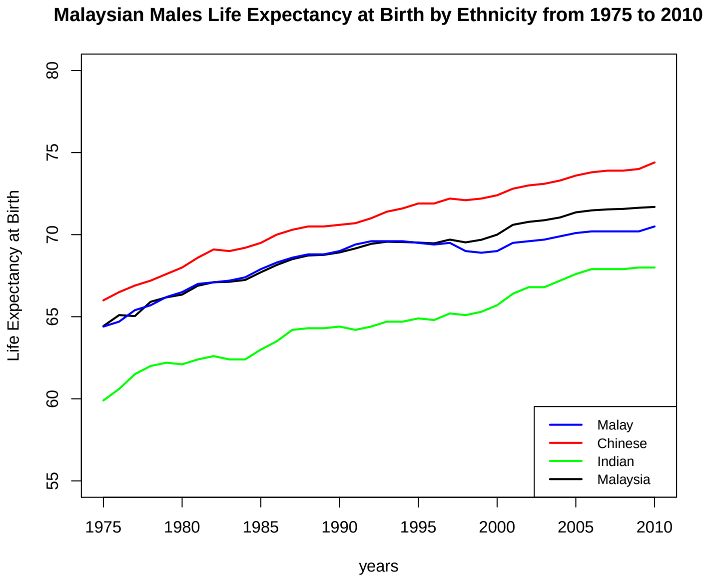
	Malay		
	Male	Female	Overall
20-year forecast			
Poisson Lee & Carter	0.157	0.182	0.133
Poisson common factor	0.229	0.129	0.179
Weighted functional	0.150	0.161	0.156
Product-ratio functional	0.238	0.094	0.166
	Chinese		
	Male	Female	Overall
20-year forecast			
Poisson Lee & Carter	0.144	0.136	0.140
Poisson common factor	0.150	0.111	0.131
Weighted functional	0.138	0.185	0.162
Product-ratio functional	0.165	0.120	0.142
	Indian		
	Male	Female	Overall
20-year forecast			
Poisson Lee & Carter	0.155	0.187	0.171
Poisson common factor	0.173	0.260	0.216
Weighted functional	0.166	0.183	0.174
Product-ratio functional	0.198	0.199	0.198

ethnic groups.

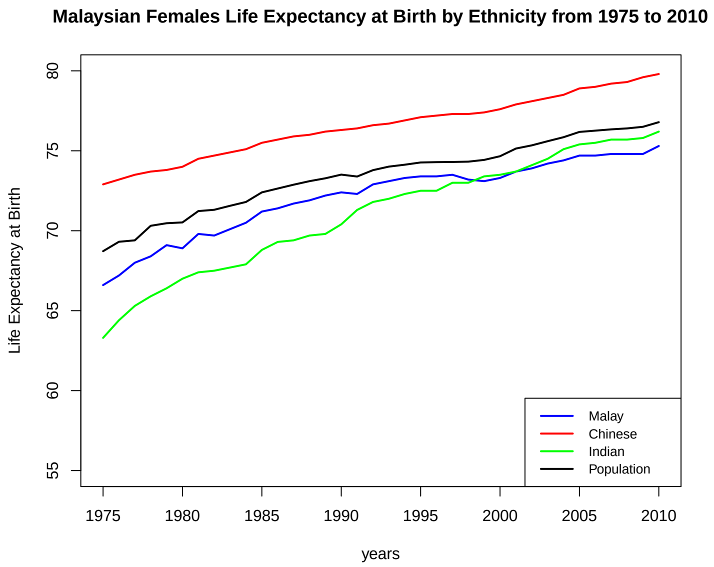
2.5.2 Ethnic-coherence

The application of coherent mortality forecasting models is extended to apply ethnic-coherence on male and female sub-ethnic populations and compare results with the gender-coherence models. Past data has suggested that Chinese mortality is consistently lower than Malay and Indian. Therefore, we attempt to incorporate Chinese data to forecast Malay and Indian mortality and report the impact of different type of coherency on the accuracy of coherent forecasts.

The overall errors (the average of Malay, Chinese and Indian) in Table 2.10 shows that the association of lower mortality groups of the same gender in the sub-population's model can improve the forecast of high mortality groups better than the association of lower mortality group of opposite gender. For example, coherent



(a)



(b)

Figure 2.7: Malaysian observed life expectancy at birth by ethnic groups from 1975 to 2010 for males (a) and females (b)

models that account for Chinese male mortality as part of the mortality reference for Malay male and Indian male (ethnic-coherence) can generally improve the forecasts of Malay males and Indian males. As can be seen from Table 2.10, the use of coherent rather than independent models reduces the error of Malay females from 0.182 to 0.142 and from 0.161 to 0.156. Similarly, the forecast errors of independent models are reduced from 0.187 to 0.152 and from 0.183 to 0.129 for Indian females. It is noteworthy that these improvements are attained at the expense of accuracy for Chinese female mortality, for example as indicated by the increase of errors from 0.136 to 0.179. Though coherent models consistently increase the forecast error of independent models for Chinese males, results for Malay males and Indian males are mixed, resulting in the ethnic-coherence models underperforming the independent models in terms of overall errors.

In addition, the results show that the association of lower mortality groups of the same gender in the sub-population's model can improve the forecast of high mortality groups better than the association of lower mortality group of opposite gender. For example, ethnic coherence models (that account for Indian female, Malay female and Chinese female mortality as part of the mortality reference) for Indian females, outperform independent models, whereas when using gender coherence, coherent models underperform independent models. Based on these findings, we suggest that the ethnic-coherence models are more accurate than the gender-coherence models for forecasting the mortality of Indian females.

2.6 Discussion

2.6.1 Coherent mortality forecasts for gender sub-populations in Malaysia and Australia

2.6.1.1 The comparison between coherent and independent models

The comparison of mortality forecasts of coherent models (Poisson common factor and product-ratio functional) and their independent versions (Poisson Lee & Carter and weighted functional), shows that the coherent models are more accurate than the independent models for both genders in Australia. In contrast, the coherent models are less accurate than the independent models for Malaysian males, but produce better results for females. In term of overall accuracy, the

Table 2.10: Mean Absolute Forecast Errors (*MAFE*) by ethnic and sex in Malaysia. Ethnic-coherence imposed on coherent models for Males and Females.

Malaysian males	**Malay**	**Chinese**	**Indian**	**Overall**
20-year forecasts				
Poisson Lee & Carter	0.157	0.144	0.155	0.152
Poisson common factor	0.148	0.187	0.169	0.168
Weighted functional	0.150	0.138	0.166	0.151
Product-ratio functional	0.162	0.167	0.150	0.160
Malaysian females	**Malay**	**Chinese**	**Indian**	**Overall**
20-year forecasts				
Poisson Lee & Carter	0.182	0.136	0.187	0.168
Poisson common factor	0.142	0.179	0.152	0.157
weighted functional	0.161	0.185	0.183	0.176
Product-ratio functional	0.156	0.185	0.129	0.157

coherent models perform less well than independent models for Malaysia. The better performance of the coherent models for Australia is in line with the findings of Hyndman et al. (2013) which show that coherent models tend to be more accurate overall than independent models for Swedish data. It may be that coherent models perform better than independent for developed countries, and are less accurate for developing countries like Malaysia. For future works, it might be possible to include a large number of developed and developing countries so that a generic relationship between developed and developing countries can be estimated.

It is noteworthy that the accuracy of the coherent models for Malaysian females is achieved at the expense of accuracy of Malaysian male mortality. Similarly, Hyndman et al. (2013) found coherency improved the accuracy of the mortality forecast of Swedish males at the expense of accuracy of Swedish female mortality. According to Yasmeen (2010) this trend is related to the first age-component of the mortality reference ($\beta_{x,l}$) that might be consistent with the first age-component of one group than another. Thus, future research is needed to further investigate the accuracy of coherent models for other less developed countries.

A better overall performance of coherent models compared to independent models for Australia is further confirmed by male to female death rate forecast ratios. However, the data suggests that the accuracy of the coherent models varies between different age groups. This might be due to the fact that coherent models were designed to produce non-divergent sub-populations forecasts, and therefore they tend to perform better than the independent models if the differentials between male and female mortality in particular groups are within a defined constant. For example, coherent models outperform independent models for Malaysian infant, children, old and oldest old age groups and at the same time significantly under perform independent models for the young adult and middle-age groups. A poorer performance for young adult and middle-age groups might be due to a diverging gap between male and female mortality, which contributes to the larger errors for the overall accuracy in Malaysia. Furthermore, the life expectancy forecasts show that coherent models tend to produce a smaller forecast gender gap which is in contrast with recent trends in Malaysia and is aligned with recent trend in Australia. Indeed, Malaysian life expectancies for males and females in recent years have been diverging due to a slow increase in male life expectancy that may be explained by the fluctuations in death rates among young male adults. Therefore, the short-term accuracy of coherent models appears to be strongly influenced by the constant differential of mortality rates between sub-populations. In other words, if some signs of dissimilar patterns are discernible: male and female mortality, coherent models may not be the best models to forecast those sub-populations.

There is some evidence from our research that indicates the constant differential between male and female mortality is achievable through a careful choice of fitting period. Although coherent models are less accurate than independent for Malaysia in 20-year forecasts, our results show that these models perform better than independent models in 10-year forecasts. A shorter forecast period extends the fitting period to include more recent linear decreasing rates in male mortality hence the rates tend to be proportional to female rates. In this case, the non-divergent forecast from coherent models is more consistent with the observation. This finding suggests that coherent models may in the future be better suited to the sub-populations of Malaysia, provided that the recently observed decreasing pattern of death rates for males, which is consistent with that for females continues in the future.

2.6.1.2 The comparison between two coherent models

To the best of our knowledge, the comparison of the forecast accuracy between the coherent models has not been documented in the literature before. This research fills the gap by comparing two most recent coherent models called product ratio functional and Poisson common factor. These two models adopt different statistical procedures that may impact the accuracy of forecasts in different ways.

This study finds that product ratio functional model produces slightly better forecasts than Poisson common factor for Australia in all forecast components: log mortality rates, male to female mortality ratios and life expectancy at birth. One of the possible reasons why the product-ratio functional model might be better is that the model was developed based on the weighted functional method framework that combines the non-parametric smoothing and geometrically decaying weight procedures. The smoothing procedure allows the observational error to be treated separately from the time series forecast while the weighting technique gives a greater weight to more recent than earlier data. Prior research confirms that that this weighted functional model successfully reduced the forecast error from other independent models for many developed countries including Australia (Shang et al. 2011). Our findings support and complement this result by showing that the use of weighted functional method in the product ratio functional models can provide the most accurate forecast for coherent models in Australia.

Nonetheless, this weighted functional technique does not seem to be suitable for Malaysian mortality and results in a less accurate performance of the product ratio functional model compared to Poisson common factor model for overall accuracy. This might be because the observed Malaysian male mortality in the forecasting period is inconsistent with the most current trend in the fitting period. Thus, applying greater weight on the most current trend may wrongly estimate the forecast trend. On the other hand, Australian male and female mortality and Malaysian female mortality are in line with the recent trends hence, weighting procedure is tended to work more effectively for this population.

2.6.1.3 The comparison between the Lee & Carter model and its extensions

Our findings support previous studies by Booth et al. (2002), Booth et al. (2006) and Shang et al. (2011) in several ways. Firstly, the original Lee & Carter model is substantially less accurate than all the Lee & Carter extensions we consider in forecasting mortality. This may be due to the limitation of the Lee & Carter model which requires a long data series for fitting hence it violates the invariant age-component and linearly decreasing time-component assumptions. Longer fitting periods produce age-component estimates that are different from the age rate of change in the forecasting period and provides structural changes for the mortality index. Therefore the Lee & Carter model may be invalid especially for a majority of developed countries.

Secondly, when forecasting life expectancy the Lee & Carter model does not necessarily produce larger errors than its extensions. For example, we find that Lee & Carter forecasts produce the highest error for Malaysian overall log death rates and that conversely it produces the least error for overall life expectancy. According to Booth et al. (2006) the life expectancy estimate involves two types of transformation of log death rates, namely exponentiation and the life table. There will be some cancellation of errors and implicit weights during the process which eventually could provide a different degree of accuracy for this measure. Therefore, it is insufficient to evaluate the accuracy of mortality forecasting model merely based on life expectancy error, the error in log death rates is essential to gain a comprehensive understanding of the forecast error. Thirdly, this study found that the weighted functional Lee & Carter extension is consistently more accurate than Poisson Lee & Carter model for independent forecasts in a developed country, Australia. This finding supports results from Booth et al. (2006) that found functional-based models produced the most accurate forecasts of log death rates. Shang et al. (2011) shows that functional methods are better than the Lee & Carter method; they found that the weighted functional version is the best among the 10 models they consider for male and female log mortality forecasts.

2.6.2 Coherent mortality forecasts for gender and ethnicity sub-populations in Malaysia

The application of coherent models to smaller sub-populations, Malay and Indigenous groups, Chinese and Indian may be advantageous to forecasters as it provides additional information and results that are specific to these particular sub-populations. For gender-coherence applications, Malaysia's mortality forecasts indicate coherent models are less accurate than independent models for overall accuracy. This result is applicable to the Malay population, which is the majority of the population. However, for Chinese, we found that coherent models are more accurate than independent models, following the results for Australia. Therefore preference between forecasting methods may differ between specific sub-populations.

Over recent decades, the life expectancy of the Chinese sub-population has been increasing and consistently higher than Malay and Indian for both genders. Our results suggest that ethnic-coherence models are more accurate than independent models for the majority of sub-populations as opposed to gender-coherence models. This suggests that the incorporation of a lower mortality of the same gender sub-population in the coherent model is more accurate than a lower mortality of opposite gender sub-population.

For the Chinese, ethnic-coherence models cause less accurate forecasts than gender-coherence forecasts. This indicates that the association of higher mortality population with lower mortality sub-populations in the model might jeopardize the accuracy for lower mortality groups. While Chinese female mortality is better forecast using gender-coherence, Chinese male mortality is better forecast individually or independently. Thus, it seems that Chinese males is the only group for which the best mortality reference is unavailable within the country.

Our findings suggest that coherent models have the potential to be more accurate than independent models even when applied to high mortality populations provided an appropriate type of coherency is chosen. Further investigations need to be done to establish the best mortality reference for the sub-populations. Other types of coherency such as urban and rural coherence or developed and developing countries coherence, would make good topics for future research.

Chapter 3

Paper 2

Coherent Stochastic Age-specific Population Forecasts by Gender and Ethnicity

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Abstract

This paper incorporates both the functional independent and the product-ratio coherent models in the cohort component population projection framework to forecast age-specific sub-populations by gender and ethnic groups. In the product-ratio model, each sub-population's demographic component rates, including mortality, fertility and net international migration, will be jointly forecast to ensure that forecast values do not diverge between sub-populations over the long run. In addition to gender-coherence, we explore another type of sub-population coherency, which is developed-developing countries coherence, where we use Australia's demographic component rates as the reference rates for Malaysia. Out-of-sample forecasts of demographic component rates and population forecasts of the different methods are evaluated. Results show that the developed-developing countries coherence model is more accurate than that of the independent and the gender-coherence models for a majority of sub-population forecasts. Developed countries with low mortality and fertility, then, have the potential to be good demographic component references for developing nations. The new coherent models are then used to develop long-term stochastic age-specific population forecasts. In comparison to the deterministic population projections of the Department Statistics of Malaysia, these coherent forecasts are ageing at a more rapid pace. Mean age-specific population forecasts for the male population aged 60 and above will reach 15% of the total population by 2034, five years earlier than that of the medium variant of the official projection.

Keywords: Stochastic Population Forecasts; Product-ratio model; Mortality Forecasting; Fertility Forecasting; Net-migration Forecasting; Cohort-component Method; Malaysia population

3.1 Introduction

Accurate age-specific population forecasts are necessary for government to implement economic and social provisions. It is crucial for demographers to understand the historical patterns of each demographic component (deaths, births and net international migrants), as they may directly influence the population forecasts. In addition, the uncertainty associated with forecast values is increasingly recognised as important in assessing the accuracy of population estimates.

This growing recognition of the uncertainty surrounding population forecasts has resulted in changes to population forecasting techniques: from deterministic to stochastic. In dealing with the uncertainty of forecasts, deterministic methods use forecasters' predefined high, medium and low future value of vital rates. There is no clear indication how these ranges are set, which has resulted in bias and under predicted forecast values in some low mortality countries (Keilman 2005, Lee & Tuljapurkar 2000). Rather than using human judgment, stochastic approaches use statistical models to measure the uncertainty of forecasts. Probability distribution functions are assigned to demographic components' time series data, hence, prediction intervals of forecast values can be estimated. Consequently, stochastic population forecasting methods have rapidly gained recognition and have been used in many developed countries including Australia, the UK, Italy Norway and the US (Hyndman & Booth 2008, Rowan & Wright 2010, Corsetti & Marsili 2012, Keilman et al. 2002, Lee & Tuljapurkar 1994).

Stochastic population forecasting methods have advanced considerably over the last two decades. Lee & Tuljapurkar (1994) were among the first to propose a stochastic population forecasting model. The methodology is based on a stochastic Leslie matrix (also known as the cohort component method), in which vital rates are modelled as stochastic time series. This method was extended by Hyndman & Booth (2008) using the functional independent model to forecast mortality rates, fertility rates and net migrants for Australia. The functional independent model had been initially developed by Hyndman & Ullah (2007) and provides a more flexible Lee & Carter (1992) framework to forecast vital rates. Moreover, the functional model was proven to be more accurate than the original Lee & Carter model and its extensions for mortality forecasts (Booth et al. 2006, Shang et al. 2011).

Although stochastic population forecasting methods have been successfully developed by researchers, methods that account for the relationship between sub-populations have been lacking. The importance of simultaneous, or coherent forecasting, between sub-populations has been discussed in the literature in the context of reducing a mortality forecast divergence (Hyndman et al. 2013, Li 2013, Li & Lee 2005, Woods & Dunstan 2014). While coherent forecasting has been used widely for mortality projections, to the best of our knowledge only Shang et al. (2013) and Hyndman (2014) use coherent methods to forecast male and female populations for the UK and Australia, respectively. Hyndman (2014) has successfully combined the stochastic population forecasting framework from Hyndman & Booth (2008) and the product-ratio coherent technique from Hyndman et al. (2013) to coherently forecast age-specific populations by gender. In Hyndman (2014) only mortality rates and net migration were forecast using the gender-coherence model and an independent model was used to forecast fertility rates. These forecast values of vital rates were then integrated using the cohort component method to get population forecasts.

In this paper, we adopt the coherent stochastic population forecasting method from Hyndman (2014) to forecast the age-specific Malaysian population. We extend Hyndman's (2014) model in three ways. Firstly, our research demonstrates that the same product-ratio coherent framework can be successful applied to all vital rates, that is, we extend this approach from mortality and net migration to include fertility rates. Secondly, we explore another possible type of coherence, developed-developing countries coherence, to forecast each demographic component. This type of coherency is used as global mortality and fertility convergence (Wilson 2001, Wilmoth 1998, Moser et al. 2005, Garbero & Sanderson 2012, Norheim 2014) is widely observed. Thirdly, we use the coherent population forecasting method to forecast age-specific population by ethnicity. Population forecasts by ethnic groups are important for a multi-racial country like Malaysia in order to evaluate ethnic differences in vital rates in the future population composition (Rees et al. 2008).

Each demographic component—mortality and fertility rates and net international migration—will be forecast using different stochastic methods, including independent, gender coherence and developed-developing country coherence. For developed-developing country coherence, we use Australian demographic rates as the reference. We choose Australia because Malaysian mortality and fertility has been converging towards lower values which most developed countries, including Australia, have experienced in previous years. Moreover, Australia and Malaysia share some common characteristics, as both are multi-racial countries located in the same Southeast Asian region and members of the Commonwealth of nations. Out-of-sample forecast errors are evaluated and compared across the independent model, gender coherence model and developed-developing countries coherence model. The developed-developing countries coherence models provide the least forecast errors for Malaysian males and females, and four out of six ethnic sub-populations. The most accurate out-of-sample forecasting models are used for the future long-term age-specific population forecasts. The long-term stochastic population forecasts are compared with Malaysia's deterministic official population projection from the Department of Statistics Malaysia (*DoSM*) from 2010 to 2030.

The paper is structured as follows. Section 3.2 discusses observed and current trends in Malaysian demographic components—mortality, fertility and net migration. Section 3.3 explains the data we use to forecast demographic components and populations. Methods for stochastic coherent population forecasting are described in Section 3.4. In Section 3.5 we evaluate the accuracy of the out-of-sample demographic components and population forecasts of the different methods. Section 3.6 illustrates the long term stochastic forecasts of the Malaysian age-specific population by gender and ethnicity. Section 3.7 discusses our findings and section 3.8 concludes.

3.2 Population and demographic components of Malaysia

Malaysians aged 60 and above represented 5.4% of the total population in 1970, and this figure increased to 8.0% in 2010[1]. Malaysia is predicted to become an aged society by 2030, that is when the percentage of older persons reach 15% of total population (Ambigga 2011, Mahari 2011, Forsyth & Chia 2009, Ong 2002). An increase in the size of the older population will have a profound impact on economic and social provisions, particularly on pension benefits and long term care services.

Figure 3.1 shows some evidence of changes in the Malaysian population age-structure from 1970 to 2010. Total population size more than doubled, from 10.9 million to 28.6 million over that period, and follows from an increase in population size at each age group. The biggest change in Figure 3.1 is the increase (up to four fold) in the working age groups between 15 to 59 years old. The proportion of this group is greater than that of the older age groups, indicating Malaysia is still a young nation. This trend reflects the approximately triangle shape of the population pyramid in Figure 3.1(b). The large proportion of young adults aged between 15 to 29 is due to high fertility in past years. Nevertheless this proportion is expected to shrink as a result of low fertility rates in more recent years. The fact that there is a tendency for the Malaysian population to live longer, and with low fertility rates, indicates that the population of the elderly is expected to grow sharply. The population pyramid is expected to shift upward, so that the proportion of younger people decreases while the proportion of the older group increases—the evidence of population ageing.

An increase in life expectancy at birth along with a tremendous decrease in total fertility rates contribute to the population ageing process. If these trends continue in the future, Malaysia is expected to receive an increasing number of international migrants in order to overcome the shortage of young workers. According to Li et al. (2009), a low number of international immigrants entering an aged country may speed up the pace of population ageing. Therefore, we include the three important demographic components (mortality, fertility and

[1] The cut-off age for Malaysian older persons is an age of 60, which is based on the definition of elderly described in the National Older Persons Policy (2011). Age 60 is also the current pension age for government and most private sector workers(Minimum Retirement Age Act 2012).

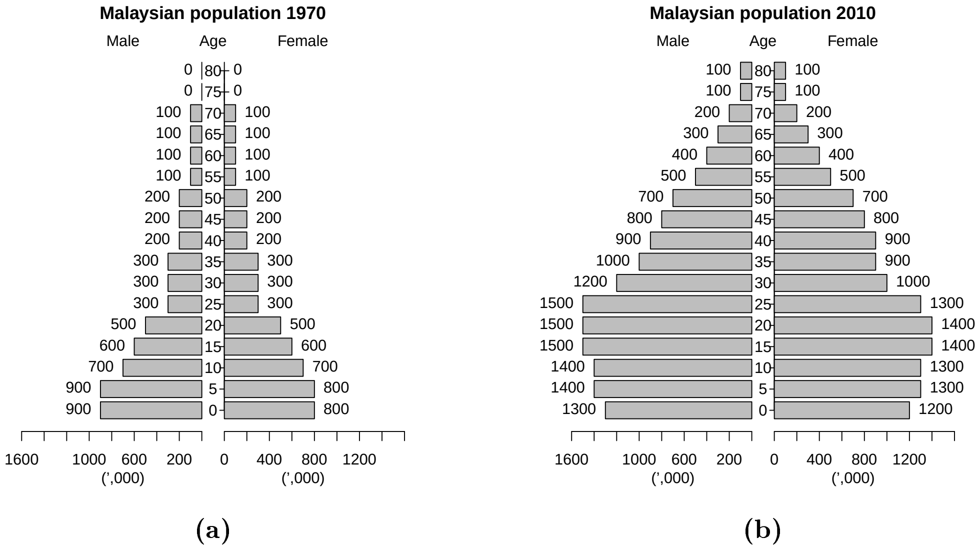


Figure 3.1: The observed Malaysian population structure in (a) 1970 and (b) 2010 in thousands, segregated by gender and quinquennial age groups. The population size has increased tremendously over the periods for each age group and for both genders. Significant increases, up to 400%, can be seen among the working age groups between 15 to 59 years old. As at 2010 Malaysia is still considered a young nation due to the approximately triangle shape of the population structure.

net international migration) in estimating the age-specific population. We discuss each of Malaysia demographic components throughout the remainder of section 3.2.

3.2.1 Mortality

The general level of Malaysian mortality has decreased considerably over recent decades. The life expectancy at birth increased from 61.45 (1970) to 71.45 (2010) for males and from 65.33 (1970) to 76.41 (2010) for females. According to Hock (2007) the long term decline in Malaysian mortality was due to medical technologies advancement, living condition enhancement and the effective controls of many tropical diseases, especially malaria.

Nevertheless, it is noteworthy that mortality decreased at different rates between ethnic groups. Chinese mortality declined faster than that of Malays or Indians. The reason why Chinese mortality was lower compared to other ethnic groups is that they earn the highest average monthly income[2], thus increasing their access to health care and medical services. In addition, different social and cultural backgrounds could also play a role. As a result of low mortality, Chinese life expectancy at birth was consistently higher than the Malay and Indian population (refer to Figure 3.2).

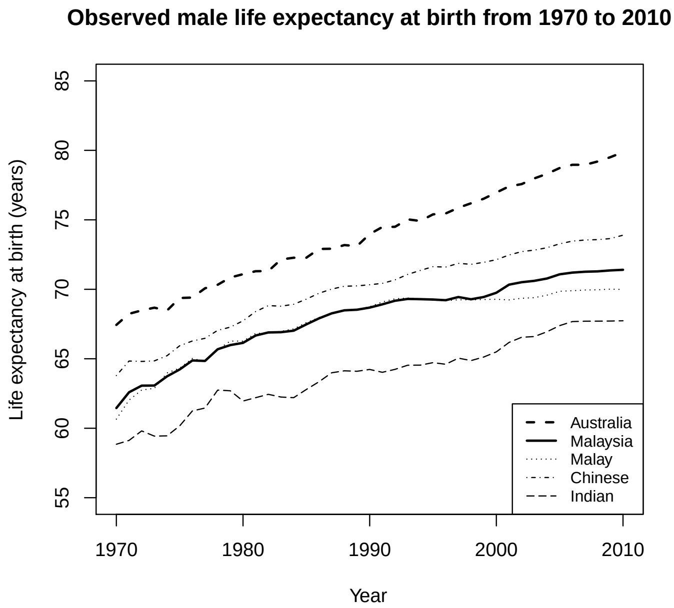
The increase in life expectancy shows no sign of abating in the majority of developed and developing countries. Malaysian life expectancy at birth is no exception, and is expected to continue increasing in the future. Figure 3.2 shows the observed life expectancy at birth of each ethnic group increased over the years, except that of Malay males—whose life expectancy at birth was almost constant since 2000. In comparison with developed countries, in this case Australia, both Malaysian life expectancy at birth for males and females were proportionally below Australia. Nevertheless, the future life expectancy at birth in Malaysia is expected to continue increasing and could reach the current Australia life expectancy level. Thus, it seems that using Australia mortality as the reference rates for Malaysian mortality is not inappropriate. Furthermore, Shair et al. (2015) found that the association of lower mortality of the same gendered sub-populations in a coherent model is more accurate than an association with the lower mortality of the opposite gendered sub-populations. Therefore, in this paper we will coherently forecast Australian males together with Malaysian males and Australian females with Malaysian females.

3.2.2 Fertility

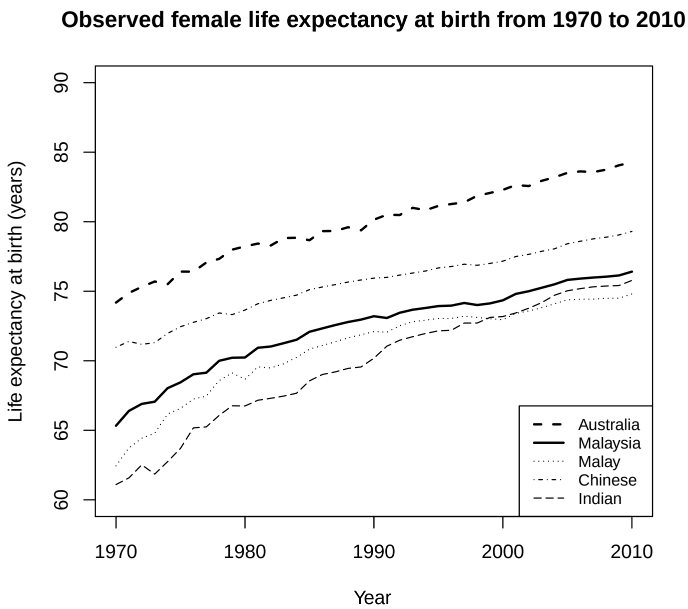
Malaysian total fertility rates (*TFRs*) have decreased tremendously from 6.28 children for every woman (aged 15 to 49) in 1958 to 2.33 children in 2013—see Figure 3.3. One factor which contributed to this change was the introduction of a national birth control program in 1966 (Mahari 2011). The objective of the policy is to reduce population growth, thereby increasing income per capita.

Similar to mortality, the rate of change in fertility varied by ethnicity. In 1958, Indians had the highest total fertility rate (7.3), followed by Chinese (6.3)

[2]Mean monthly income was obtained from Economic Planning Unit (2014), The Mean Gross Household Income by Ethnicity, and State, Malaysia, 1970–2014. The report showed that, in 2014, Chinese earned on average MYR$7,666 (USD$1,893) compared to MYR$5,548 (USD$1,370) and MYR$6,246 (USD$1,543) for Malays and Indians respectively. The conversion of Malaysian Ringgit to US Dollars is based on `http://www.xe.com/currencyconverter` as at 23rd of September 2015.



(a)



(b)

Figure 3.2: The observed Malaysian, Malaysian ethnic groups and Australian life expectancy at birth, from 1970 to 2010, for (a) males and (b) females. Life expectancy at birth has increased substantially over the years for each group. Australian life expectancy is consistently higher than that of Malaysia. Between Malaysian ethnic groups, Chinese life expectancy is the highest compared to Malays and Indians.

and Malays (5.8). These rates decreased and converged towards the replacement fertility ratio (2.0) by 2006. Indian and Chinese fertility has declined at faster rate than that of Malays and reached slightly below the replacement ratio at 1.9 and 1.8, respectively, in 2006. Malay fertility, on the other hand, decreased at slower rates and remains above the replacement ratio at 2.7 children by 2006. High fertility among Malays was attributed to low acceptance of birth control policy (Hock 2007), which was related to their religious and cultural backgrounds.

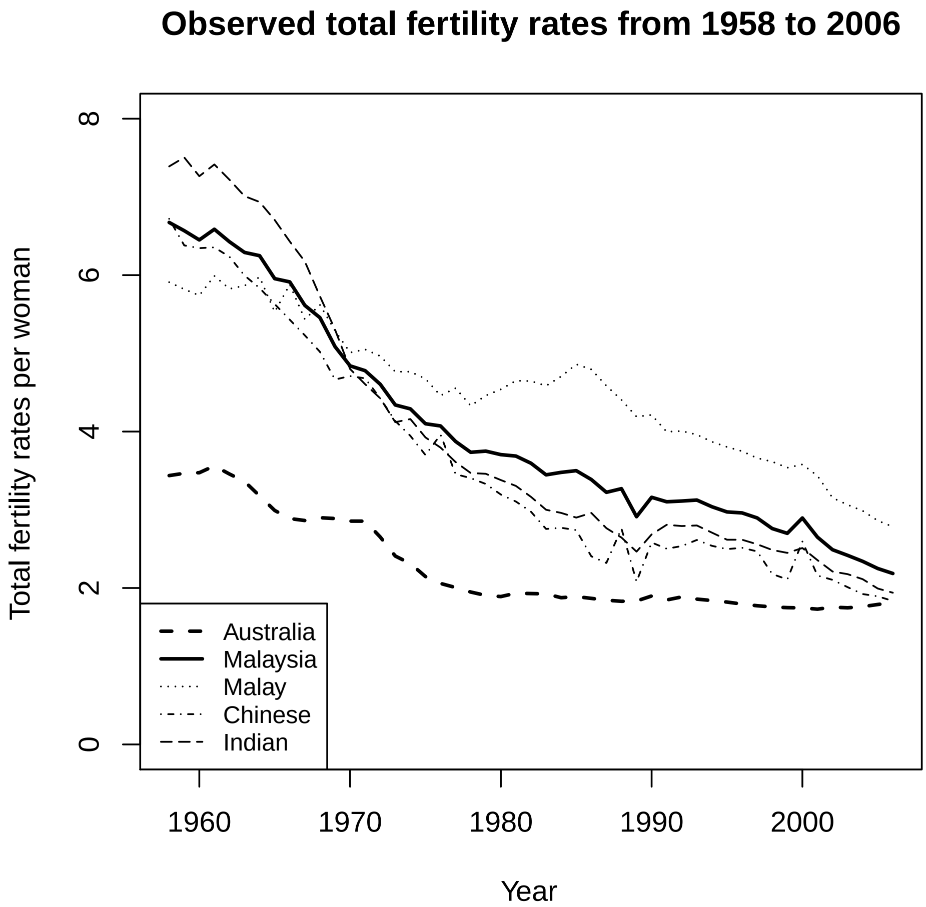
Malaysian *TFR* is expected to continue decreasing and will fall below replacement rates, a level currently experienced by many developed countries. The official population projection (under the medium variant) assumed that Malaysian *TFR* will reach 1.8 babies per woman by 2040 (Hassan 2012). This assumption is consistent with UN projections in which the high *TFRs* among developing countries are expected to decrease towards below the replacement ratio by 2050.

The majority of developed nations experienced a decrease in *TFR*s. Once fertility reached the replacement ratio or lower, the rate fluctuated around that value for decades. For example, Figure 3.3 shows that the Australian *TFR* decreased and reached below the replacement ratio value at 1.9 by 1980, then the *TFR* fluctuated around the same value after that. In 2013 Australian *TFR* was 1.88 babies per woman, which is approximately the same as the targeted *TFR* for Malaysia by 2040. Hence, using the Australian observed *TFR* as the reference rate to forecast Malaysian fertility seems reasonable.

3.2.3 Migration

Malaysia is a receiving and sending country for international migrants. According to data from the Department of Immigration Malaysia, international immigrants consist of expatriates, skilled workers, semi-skilled and unskilled workers, international students and foreign elderly (under the Malaysia My Second Home (MM2H) program). In 2006, there were a total of 2,044,805 immigrants (about 8.3% of total population). Out of these immigrants, the semi-skilled and unskilled foreign workers were the majority (91%), who came from neighbouring countries, such as Indonesia, the Philippines and Myanmar (Kanapathy 2008).

Data for Malaysian migration is also available from the census, which estimated non-Malaysian citizens who stay for six month or more in Malaysia. Nevertheless, at present, data for international migration outflows are not collected, hence the



(a)

Figure 3.3: The observed Malaysian, Malaysian ethnic groups and Australian total fertility rates per woman at reproductive ages (15–45) from 1958 to 2006. Total fertility rates of each group show a decreasing pattern converging towards the replacement ratio (2.0) over the years. In 2006, Chinese and Indian total fertility rates reached slightly below the replacement ratio at 1.8 and 1.9 respectively, whereas Malaysian and Malay total fertility rates are still above the replacement ratio, at 2.3 and 2.7. Australian total fertility rates decreased and reached below the replacement ratio at 1.9 in 1980 (27 years earlier than Chinese and Indians), remaining approximately constant thereafter.

net international migrants (inflows-outflows) cannot be estimated. In addition, the historical pattern of this component is less clear, which makes forecasting net migration difficult. In order to overcome this problem, following Hyndman & Booth (2008), we use the demographic growth-balance method to estimate the time series data of Malaysian net international migration. This demographic growth-balance method is explained in Section 3.3.1.

3.3 Data

Malaysian and Australian data required for this research included age-specific mortality rates, age-specific fertility rates, age-specific exposure to risk and age-specific population numbers.

Malaysian mortality, fertility and population data were collected from the Department of Statistics Malaysia (*DoSM*). Australia's mortality, exposures and population data were retrieved from the Human Mortality Database (2014); fertility data were obtained from the `addb` package for *R* (Hyndman 2010)[3]. Table 3.1 summarises the notation used for population variables throughout this paper.

It is noteworthy that Malaysian data are available only in quinquennial age intervals from 1958 to 2010. Earlier data has shown that there is some inconsistency in data coverage—before 1963 the eastern part of Malaysia (Sabah and Sarawak) are not included in death counts. Hence, we use data from 1970 to 2009, yielding 40 years of time series data. We include Australian data also from 1970 onwards, to be consistent with the Malaysian data. Moreover, according to Hyndman & Booth (2008), a later starting point for the fitting period is valuable to avoid the outliers and major structural changes over time.

Deaths and births can be estimated using the data noted as above. That is, $D_{t,i}^{v}(x) = m_{t,i}^{v}(x) \times E_{t,i}^{v}(x)$ and $B_{t,i}^{v}(x) = f_{t,i}^{v}(x) \times E_{t,i}^{v}(x)$, respectively. These deaths $D_{t,i}^{v}(x)$ and births $B_{t,i}^{v}(x)$, together with population $P_{t,i}^{v}(x)$, are necessary for the net international migration calculation.

[3]Note that in order to use data from `addb` package, one should also install the *demography* package developed by Hyndman (2013).

Table 3.1: Summary of notation adopted

Notation	Description
$m_{t,i}^{v}\left(x\right)$	central mortality rates of i^{th} sub-population aged x in calendar year t for v^{th} population.
$f_{t,i}^{v}\left(x\right)$	central fertility rates of i^{th} sub-population aged x in calendar year t for v^{th} population.
$E_{t,i}^{v}\left(x\right)$	exposure to risk of i^{th} sub-population aged x at 30 June in calendar year t for v^{th} population.
$P_{t,i}^{v}\left(x\right)$	population of i^{th} sub-population aged x as at 1 January in calendar year t for v^{th} population.
$D_{t,i}^{v}\left(x\right)$	deaths of i^{th} sub-population aged x in calendar year t for v^{th} population.
$B_{t,i}^{v}\left(x\right)$	birth of i^{th} sub-population age x in calendar year t for v^{th} population.
$G_{t,i}^{v}\left(x,x+1\right)$	net international migration of i^{th} sub-population aged x in the beginning of calendar year t for v^{th} population.
v	$v=1$ for Malaysia, $v=2$ for Australia, $v=3$ for Malay, $v=4$ for Chinese and $v=5$ for Indian.
i	$i=1$ for males and $i=2$ for females.
x	$x=0,1,2,\ldots,p-1,p^{+}$ where p^{+} is the oldest age group.

3.3.1 Estimation of migration data

Since out-migration data for Malaysia are unavailable, we use the growth-balance method to estimate the age-specific net international migration numbers for Malaysian males and females[4].

The growth-balance method calculates net migration as the residual between the populations in consecutive years by taking into account deaths or births that occurred in each year as follows,

$$\begin{aligned} G^v_{t,i}(B,0) &= P^v_{t+1,i}(0) - B^v_t + D^v_{t,i}(B,0) \\ G^v_{t,i}(x,x+1) &= P^v_{t+1,i}(x+1) - P^v_{t,i}(x) + D^v_{t,i}(x,x+1) \\ G^v_{t,i}\left(p-1^+,p^+\right) &= P^v_{t+1,i}\left(p^+\right) - P^v_{t,i}\left(p^+\right) - P^v_{t,i}(p-1) + D^v_{t,i}\left(p-1^+,p^+\right) \end{aligned}$$

where $G^v_{t,i}(B,0)$ refers to migration of those born in year t, $G^v_{t,i}(x,x+1)$ refers to migration in calendar year t of persons aged $x = 0,1,2,\ldots,p-2$ at the beginning of year t and $G^v_{t,i}(p-1^+,p^+)$ refers to migration in calendar of year t of person age $p-1$ and older at the beginning of year t. Similar definitions for deaths $D^v_{t,i}(B,0)$, $D^v_{t,i}(x,x+1)$ and $D^v_{t,i}(p-1^+,p^+)$ apply. Births (B^v_t) are divided by sex using the sex-ratios at birth. We use the sex-ratio at birth of 1.07 and 1.05 for Malaysia and Australia respectively throughout the years.

Figure 3.4 shows the estimated age-sex specific net international migration for Malaysia and Australia, calculated using the growth-balance method. The net international migrants fluctuate around zero for most of the age groups except for the young working-age group between 18 to 30 years old. For this young working-age group, significant positive values can be seen in both countries, indicating these countries received more immigrants than sending out migrants in order to meet labour market shortages. As Malaysia is recently ageing and moving towards high income status, an increasing number of overseas immigrants can be seen, noticeably starting from 2000 to 2005 (violet lines).

[4] See, for example, Rowland (2003) or Hyndman & Booth (2008).

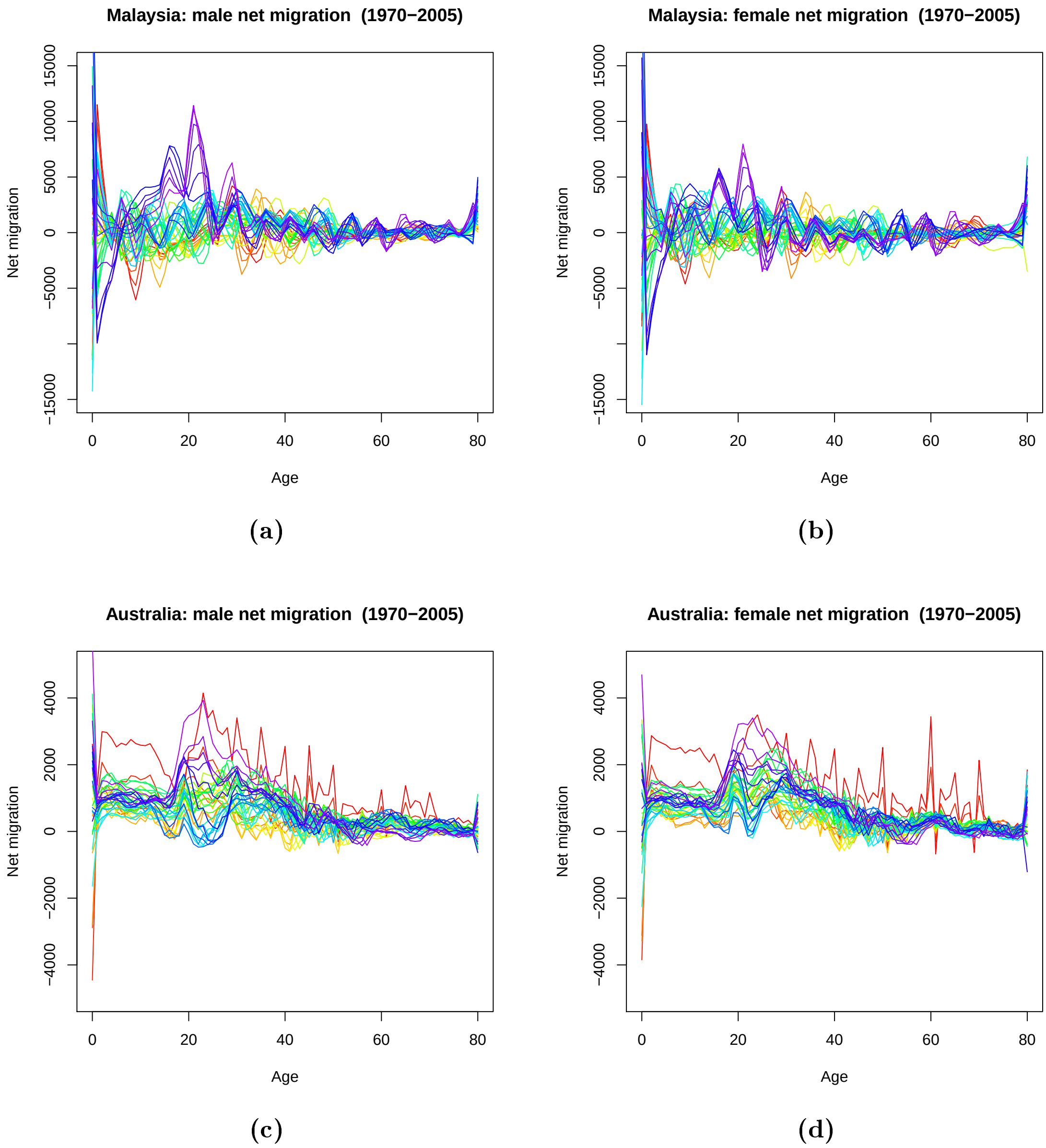


Figure 3.4: The observed net international migration in absolute numbers from 1970 to 2005 for Malaysia and Australia. The graphs were produced using the `demography` package from Hyndman (2013), in which the rainbow color palette was used to represent data for each year. The first few years are shown in red, followed by orange, yellow, green, blue and indigo with the last few years plotted in violet. We can see from the graphs, the number of migrants fluctuated around the zero value for most of the age groups. Significant positive values of net migrants are apparent only for the young working-age group between 18 to 30 years old in both countries. This pattern can be seen as early as 1970s (red lines) for Australia but started in later years, since 2000s, for Malaysia (violet lines).

3.3.2 Interpolation of quinquennial-ages into single-aged data

3.3.2.1 Interpolation of population data

We adopt a well known interpolative four-term third-difference solution (the Karup-King method) to interpolate Malaysian quinquennial-aged population data to yield single-aged population data[5]. Bijak & Kupiszewska (2008) recently used this method in estimating the populations of 31 European countries.

The interpolated values for population data are computed by multiplying a given quinquennial-aged value and its neighboring ones by a set of corresponding coefficients $c(i, j)$. Then, these products are accumulated. The set of coefficient values is obtained from Bijak & Kupiszewska (2008), and is given in Appendix 3.A. For example, if we want to split one of the middle quinquennial-aged population values, N_i, into five single-age populations n_1, n_2, n_3, n_4 and n_5 then:

$$
\begin{aligned}
n_1 &= c_{1,1} \times N_{i-1} + c_{1,2} \times N_i - c_{1,3} \times N_{i+1}, \\
n_2 &= c_{2,1} \times N_{i-1} + c_{2,2} \times N_i - c_{2,3} \times N_{i+1} \\
&\vdots \\
n_5 &= c_{5,1} \times N_{i-1} + c_{5,2} \times N_i - c_{5,3} \times N_{i+1}
\end{aligned}
$$

Suppose the Malaysian female population who are in the middle age group (25 to 29 years old) in 2006 is 1,062,700. And suppose we want interpolated the value to single ages 25, 26, 27, 28 and 29. Further, suppose the population before and after the 25 to 29 group (which are the 20 to 24 and 30 to 34 groups) are 1,278,600 and 955,400 respectively. Hence, from the above equations, the 25, 26, 27, 28 and 29 years old female population can be calculated as follows,

$$n_{25} = 0.064 \times 1,278,600 + (0.152) \times 1,062,700 - (-0.016) \times 955,400 = 258,647$$

$$n_{26} = 0.008 \times 1,278,600 + (0.224) \times 1,062,700 - (-0.032) \times 955,400 = 278,846$$

$$n_{27} = -0.024 \times 1,278,600 + (0.248) \times 1,062,700 - (-0.024) \times 955,400 = 255,793$$

$$n_{28} = -0.032 \times 1,278,600 + (0.224) \times 1,062,700 - (0.008) \times 955,400 = 189,486$$

$$n_{28} = -0.016 \times 1,278,600 + (0.152) \times 1,062,700 - (0.064) \times 955,400 = 79,927$$

[5]The details of this method can be found in Siegel & Swanson (2004), for example.

Note that the population numbers that we used here are from the observed Malaysia population data that we gathered from the Department of Statistics Malaysia.

3.3.2.2 Interpolation of abridged life table and vital rates

Malaysian vital rates and life tables from the *DoSM* are available only in abridged form. However, single-age mortality and fertility rates are necessary, especially to perform developed-developing country coherent forecasts. Both countries' data must be consistent in order to be able to combine and fit it into the same model.

We used the interpolation method from Li & Chan (2004) to estimate the complete life table and single-age vital rates. The five-year age rates are treated as the single-age rate of the mid-point of its corresponding age group. For example, for the middle age group, we set $m^v_{t,i}(7)$ as ${}_5M_5$, $m^v_{t,i}(12)$ as ${}_5M_{10}$ ... and $m^v_{t,i}(77)$ as ${}_5M_{75}$. For the open age group 80 and above, M_{88} is set as a single-age rate as we assume the last age is 100. For infant and child mortality, $m^v_{t,i}(0)$, is treated as ${}_1M_0$ and $m^v_{t,i}(1)$ is taken as ${}_4M_1$. The remaining interpolation scheme is described below[6].

$$m^v_{t,i}(x) = \begin{cases} \frac{1}{5}({}_5M_5 -_4 M_1)(x-2) +_4 M_1, & \text{for } x = 2,3,4,5,6 \\ \frac{1}{5}({}_5M_k + 3 -_5 M_k - 2)(x-k) +_5 M_k - 2, & \text{for } x = k,\ldots,k+4 \\ & \text{where } k = 7,12,17,\ldots,72, \\ \frac{1}{11}({}_{20}M_{80} -_5 M_{75})(x-72) +_5 M_{75}, & \text{for } x = 73,74,\ldots,87 \\ \frac{1}{12}(1 -_{20} M_{80})(x-88) +_{20} M_{80}, & \text{for } x = 88,89,\ldots,100. \end{cases}$$

where ${}_jM_k$ is the five-year age vital rates for persons in age group k to $k+j-1$.

3.4 Stochastic coherent population forecasting

We produce three different type of models to forecast each demographic component: an independent model, a gender coherence model and a developed-developing countries coherence model. While independent and gender coherence models apply only to Malaysian data, developed-developing countries co-

[6]Note that for fertility rates, only middle age group equations are applied; the first and last equations are inapplicable.

herence models utilises both Australian and Malaysian data. For the gender and developed-developing countries coherence models, we use the product-ratio model framework from Hyndman et al. (2013) described in the next section. For the independent model, we adopt the functional method given in the Hyndman & Booth (2008) and Hyndman & Ullah (2007) papers.

The sample paths of forecast demographic rates are simulated using Monte Carlo simulation, giving the forecast distribution for all ages in future years. These simulated rates are used to estimate the number of births, deaths, net migrants and population, which are then combined using the cohort-component method to obtain the age-specific population forecasts with prediction intervals.

3.4.1 Product-ratio coherent model for mortality, fertility and net migration

Let $Y^v_{t,i}(x)$ represent either the observed mortality rate $m^v_{t,i}(x)$, fertility rate $f^v_{t,i}(x)$ or net migration number for $G^v_{t,i}(x, x+1)$. These observed values are smoothed using the following equation,

$$Y^v_{t,i}(x) = s^v_{t,i}(x) + \sigma^v_{t,i}(x)\epsilon_{t,i,x}, \tag{3.1}$$

where $s^v_{t,i}(x)$ is the underlying smooth function over ages for demographic component rates and $\epsilon_{t,i,x}$ is the standard error, which allows the variance $\sigma^v_{t,i}(x)$ to change over age and time. For smoothing, non-parametric penalised regression splines are applied. Mortality data are constrained to be monotonically increasing at age $x > c$. On the other hand, fertility data are constrained to be concave.

The smoothed vital rates $s^v_{t,i}(x)$ are then transformed into product and ratio functions as in equations (3.2) and (3.3), respectively,

$$p_t(x) = \left[\prod_{i=1}^{n} s^v_{t,i}(x)\right]^{1/n}, \tag{3.2}$$

$$r_{t,i}(x) = \frac{s^v_{t,i}(x)}{p_t(x)}, \tag{3.3}$$

where $p_t(x)$ is the geometric mean of n sub-populations ($i = 1, 2, \ldots, n$) and $r_{t,i}(x)$ is the ratio function of the i^{th} sub-population which measures the difference between the i^{th} sub-population's vital rates and the geometric mean.

We illustrate the product function for the gender coherence model of the Malaysian population and the product function for the developed-developing countries coherence model of the male sub-population in equations (3.4) and (3.5).

$$p_t(x) = \left[s^1_{t,1}(x) \times s^1_{t,2}(x)\right]^{1/2} \tag{3.4}$$

$$p_t(x) = \left[s^1_{t,1}(x) \times s^2_{t,1}(x)\right]^{1/2} \tag{3.5}$$

Following Hyndman & Booth (2008), these product and ratio values were transformed to $p^*_t(x)$ and $r^*_{t,i}(x)$ using the Box-Cox transformation as follows.

$$p^*_t(x) = \begin{cases} \frac{1}{\lambda}([p_t(x)]^\lambda - 1) & \text{if } 0 < \lambda \leq 1; \\ \ln(p_t(x)) & \text{if } \lambda = 0 \end{cases}$$

$$r^*_{t,i}(x) = \begin{cases} \frac{1}{\lambda}([r_{t,i}(x)]^\lambda - 1) & \text{if } 0 < \lambda \leq 1; \\ \ln(r_{t,i}(x)) & \text{if } \lambda = 0 \end{cases}$$

The Box-Cox family of power transformations optimises the normality of variables and stabilises variance. One advantage of this method is it eliminates the need to randomly test different kinds of transformations in determining the optimum transformation (λ) for the data (Osborne 2010). If $\lambda = 1$, then no transformation is needed. This kind of transformation is suitable for any variable which includes negative values. Following Hyndman & Booth (2008), we use no transformation for net migration data. For mortality, we adopt a common type of transformation used widely in the mortality forecasting literature, which is the natural logarithm ($\lambda = 0$). Fertility transformation is uncertain and varies between $0 < \lambda \leq 1$. We adopt the fertility transformation used by Hyndman & Ullah (2007), which is $\lambda = 0.4$.

The transformed product and ratio functions were then incorporated into the independent functional model of Hyndman & Ullah (2007), giving equations (3.6) and (3.7)

$$p^*_t(x) = ap(x) + \sum_{l=1}^{L} \beta_l(x) K_{t,l} + ep_t(x) \tag{3.6}$$

$$r^*_{t,i}(x) = ar_i(x) + \sum_{l=1}^{L} b_{i,l}(x)k_{t,i,l} + er_{t,i}(x) \tag{3.7}$$

where $\beta_l(x)$ and $b_{i,l}(x)$ are the age-components of the product and ratio functions and $K_{t,l}$ and $k_{t,i,l}$ are the corresponding time-components that change over time. These time-components are sometimes known as the mortality, fertility or net migration index. Parameters of both the age and time components are estimated using the principal components decomposition of $[p^*_t(x) - ap(x)]$ and $\left[r^*_{t,i}(x) - ar_i(x)\right]$ respectively. The $ap(x)$ and $ar_i(x)$ are the means taken over time for $p^*_t(x)$ and $r^*_{t,i}(x)$, respectively, while $ep_t(x)$ and $er_{t,i}(x)$ are the independent and identically distributed errors. The variable L is the required number of decomposition components, which is not fixed and is specified before modelling. According to Hyndman & Booth (2008), a model with an L of six is good enough to explain variation in data and provides more accurate forecasts than a model with L less than six.

For the independent model, the smoothed vital rates $s^v_{t,i}(x)$ will be used in a functional data model, without transforming the rates into product and ratio functions

$$s^v_{t,i}(x) = \mu_i(x) + \sum_{l=1}^{L} \phi_{i,l}(x)\gamma_{t,i,l} + e_{t,i}(x) \tag{3.8}$$

where $\phi_{i,l}(x)$ and $\gamma_{t,i,l}$ are the age-components and time-components of either mortality rates, fertility rates or net migrants. Both parameters are estimated from the principal components decomposition of $\left[s^v_{t,i}(x) - \mu_i(x)\right]$. The $\mu_i(x)$ is the mean taken over time for $s^v_{t,i}(x)$ and $e_{t,i}(x)$ are errors.

3.4.1.1 Mortality, fertility and net migration forecasts

Next, we forecast only the time-component of the product ($K_{t,l}$) and ratio ($k_{t,i,l}$) functions for each demographic component: mortality, fertility and migration.

Due to non-stationarity patterns, the time-components of the product functions, $K_{t,l}$, are best forecast using non-stationary autoregressive integrated moving average, ARIMA(p, d, q), models. The time-component, on the other hand, of the ratio functions $k_{t,i,l}$, is forecast using any stationary autoregressive moving average, ARMA(p, q), or autoregressive fractionally integrated moving-average, ARFIMA(p, d, q), process. These stationary models are used to ensure the demographic rate forecasts are coherent between sub-populations. For two or more sub-populations, the ratio functions will also satisfy the constraint that $r_{t,1}(x)r_{t,2}(x)\dots r_{t,n}(x) = 1$.

The time-component forecasts were then multiplied by the corresponding age-components, giving forecasts of the product and ratio function of the demographic components. If $\hat{K}_{n+h|n,l}$ and $\hat{k}_{n+h|n,i,l}$ are the h-step forecasts of the product and ratio functions' time-components, then the h-step forecasts of the product and ratio functions are estimated using the following

$$\hat{p}^*_{n+h|n}(x) = ap(x) + \sum_{l=1}^{L} \beta_l(x)\hat{K}_{n+h|n,l} \tag{3.9}$$

$$\hat{r}^*_{n+h|n,i}(x) = ar_i(x) + \sum_{l=1}^{L} b_{i,l}(x)\hat{k}_{n+h|n,i,l} \tag{3.10}$$

Age-specific values of each of mortality, fertility and net international migration forecasts for the i^{th} sub-population are estimated by multiplying the $\hat{p}^*_{n+h|n}(x)$ with $\hat{r}^*_{n+h|n,i}(x)$. It should be noted that up to this stage the forecasts were transformed rate—for example, in natural log values for mortality. Hence, in order to estimate the forecasts in the original scale, forecasts require inversion (such as exponentiating the mortality forecasts).

3.4.1.2 Forecast Variances

All terms in equations (3.9) and(3.10) are uncorrelated, hence the variance of each term can be added together such that

$$Var\left[\hat{p}^*_{n+h|n}(x)\right] = \sigma^2_{ap}(x) + \sum_{l=1}^{L} \beta_{i,l}(x)^2 \upsilon_{n+h|n,l} + S_{ep}(x) \tag{3.11}$$

$$Var\left[r^*_{n+h|n,i}(x)\right] = \sigma^2_{ar_i}(x) + \sum_{l=1}^{L} b_{i,l}(x)^2 \delta_{n+h|n,i,l} + S_{er_i}(x) \tag{3.12}$$

where $\upsilon_{n+h|n,l}$ is the variance of $\hat{K}_{n+h|n,l}$ and $\delta_{n+h|n,i,l}$ is the variance of $\hat{k}_{n+h|n,i,l}$, which are both retrieved from the forecast time series models of time components. Values $\sigma^2_{ap}(x)$ and $\sigma^2_{ar_i}(x)$ are the variances of the smoothed means estimated from the smoothing method and $S_{ep}(x)$ and $S_{er_i}(x)$ are calculated by averaging $ep_t(x)$ and $er_{t,i}(x)$, respectively, for each x.

The observaed variance was added to the forecast variances respecting the nature of the data. Here, both deaths and births are assumed to have a Poisson distribution. For migration, non-parametric error estimates were used.

3.4.2 Stochastic cohort component population forecasting method

Population forecast uncertainties were simulated using the Hyndman & Booth (2008) cohort-component projection method described below.

A large, $N = 1,000$ random sample path of the time-component of the product, $K_{t,l}$, and ratio, $k_{t,i,l}$, were generated from the time series model using a Monte Carlo simulation approach. The random values of the errors of $ep_t(x)$ and $er_{t,i}(x)$, were also generated using the bootstrap method in which the estimated values are randomly re-sampled from the model. The forecast and random sample of product and ratio functions were multiplied to get either $m^v_{t,i}(x)$, $f^v_{t,i}(x)$ or $G^v_{t,i}(x, x+1)$.These forecasted demographic component rates random sample paths are used to estimate deaths, births and net-migration.

We began the age-specific cohort-component population forecasts by, first, adjusting the population with migration, so that the calculation of births and deaths will account for migrants. The simulated $G_{t,i}(B, 0)$, $G_{t,i}(x, x+1)$ and $G_{t,i}(p-1^+, p^+)$ were assumed to spend half a year exposed to death or birth. Thus, half of the simulated $G_{t,i}(x, x+1)$ was added to the population aged x on 1 January of year t, and the other half to the population aged $x+1$ at the end of year t, giving the population adjusted for the first half of migration. For $G_{t,i}(B, 0)$, half is added to the birth population in year t and half to the population aged 0 at the end of year t. At the open-ended age, $G_{t,i}(p-1^+, p^+)$ is equally divided between migrants aged $p-1^+$ and p^+. After the population has been adjusted for migration, we turned to the question of simulating the mortality to determine the random number of deaths.

We used a simulated sample path of mortality $m^v_{t,i}(x)$ and the mid-year population at calender year t to determine deaths. However, the mid-year population at calender year t depends on the number of deaths. To deal with this circularity, the expected number of cohort deaths was obtained using the simulated values of $m^v_{t,i}(x)$ and the population adjusted for the first half of migration at year t. These deaths were used to estimate the population adjusted for the first half of migration at year $t+1$ year and hence the mid-year population. The multiplication of the estimated mid-year population and $m_{t,i}^{v}(x)$ gives deaths in year t. Population on 1 January of year t minus deaths plus the second half of net-migration, yields the population on 1 January of year $t+1$, P_{t+1}.

Next, we estimated births using the simulated age-specific fertility rates $f_{t,i}^{v}(x)$ and the population adjusted for half a year of net migration. These age-specific births were accumulated to give the simulated total births in calender year t. The segregation of newborns according to gender is done by applying the estimated total births with the male to female ratio at births. Then mortality was also applied to birth using the same procedure described in previous paragraph to obtain deaths for this infant group.

Finally, we combined simulated deaths, births and migrants to generate the population on 1 January for the next year, P_{t+1}. This procedure was repeated for the entire h forecast years ($t = n+1, n+2, \ldots, n+h$) and for each sample path[7]. The cohort-component method estimates population for the following year ($t+1$) by adding births and net migration that occur between $(t, t+1)$ to the population in year t. Deaths within the interval will be deducted from the population at t. Population forecasting is done separately for each i^{th} sub-population and age group[8]. Thus we have

$$\begin{aligned}
P_{t+1,i}(B,0) &= B_{t,i} - D_{t,i}(B,0) + G_{t,i}(B,0) \\
P_{t+1,i}(x) &= P_{t,i}(x,x+1) - D_{t,i}(x,x+1) + G_{t,i}(x,x+1) \\
P_{t,i}(p^{+}) &= P_{t,i}(p^{+}) + P_{t,i}(p-1) - D_{t,i}(p-1^{+},p^{+}) - G_{t,i}(p-1^{+},p^{+})
\end{aligned}$$

3.5 Evaluation of out-of-sample population forecasts

In this section, we illustrate the age-specific mortality, fertility and net international migration forecasts using the independent functional model, gender coher-

[7] With thousands of sample paths for each demographic component, computation requires the use of computer software. In order to perform such stochastic population forecasts, Hyndman (2013) developed the `pop.sim` function in the `demography` package using the R programing language. The `pop.sim` code is based on pre-specified models. For example, the coherent product-ratio model can be applied only for mortality and migration but not fertility. For fertility, pop.sim uses an independent functional model. To overcome this limitation, the code was modified.

[8] For a more comprehensive description of the method, refer to Hyndman & Booth (2008).

ence model and developed-developing countries coherence model. These different demographic component forecasts of different methods were then combined using the cohort component method to estimate the age-specific population by gender and ethnicity.

The out-of sample age-specific sub-population forecasts were evaluated and compared across methods by gender (section 3.5.1) and ethnicity (section 3.5.2). In order to perform forecast evaluation, the 40-year Malaysian observation rates from 1970 to 2009 were divided into two parts: an estimation part and an evaluation part. The first consisted of 25 years in-sample data from 1970 to 1994 and latter included the remaining 15-year out-of-sample data from 1995 to 2009. Data were fitted to the models in the estimation part, while the comparison between forecast values and the observed rates was done in the evaluation part.

Australian and Malaysian demographic component rates are combined only in the developed-developing countries coherence model. The Malaysian males and Australian males, and Malaysian females and Australian females were jointly forecast in this model. In addition, apart from using the same estimation period from 1970 to 1994, the Australian estimation period is also lagged by 10 and 20 years. We label these lagged model as developed10-developing countries coherence and developed20-developing countries coherence, respectively[9]. The estimation periods of the different models are summarised in Table 3.2.

The out-of-sample forecast evaluation was performed purposely to identify the most accurate model to be used for the long-term population forecast described in section 3.6.

3.5.1 Out-of-sample population forecast accuracy by gender

The accuracy of the out-of-sample population forecasts were evaluated using the mean absolute forecast errors ($MAFE$s) measurement[10] from equation (2.9). We include several combinations of demographic forecasting models to produce eight forecast series for both Malaysian males and females. These forecast series and

[9]Periodically we abbreviate the developed-developing countries coherence model as "developed", the developed10-developing countries coherence model as "developed10" and the developed20-developing countries coherence model as "developed20".

[10]Means are taken over the absolute difference between the mean of the future sample path of forecast values and the observed out-of-sample data.

Table 3.2: The fitting periods of different demographic component models in performing the 15-year Malaysia population forecasts. The estimation periods of Australia are lagged by 10 and 20 years for the developed10-developing countries coherence and developed20-developing countries coherence models, respectively.

Model	Estimation period	
	Australia	Malaysia
Independent	-	1970–1994
Gender coherence	-	1970–1994
Developed-developing countries coherence	1970–1994	1970–1994
Developed10-developing countries coherence	1960–1984	1970–1994
Developed20-developing countries coherence	1950–1974	1970–1994

their population forecast errors are presented in Table 3.3.

The comparison between the independent population model (series 1) and the gender coherence population model (series 2) shows the gender coherence model outperformed the independent model for males but underperformed for females. Note that the accuracy of the gender coherence model for males was achieved at the expense of the accuracy of the female population (Hyndman et al. 2013).

Interestingly, results show that the accuracy of Malaysian male and female population forecasts can be further improved using the developed-developing countries coherence models (series 3 to 8). It is noteworthy that, for these type of models, the demographic component rates of Australia males and females was combined with Malaysian males and females, respectively, to coherently forecast each Malaysian male and female vital rate. Without using Australia lagged data, forecast series 3 performed better than series 6, indicating that the Malaysian population is best forecast using the developed coherence model for mortality and net-international migration, with an independent model for fertility.

We explored the possibility of using Australian lagged in-sample data to improving Malaysian population forecast accuracy. The 10-year lag and the 20-year lag model appear in series 4, 5, 7 and 8. As can be seen in Table 3.3, the lagged Australia data models outperformed other models. For instance, forecast series 7 is the most accurate for males whereas series 5 is the most accurate for females. In terms of the overall[11] results, forecast series 7 substantially reduces the forecast error relative to the other models, providing the least forecast errors. The

[11] In the overall case, the average is taken over male and female errors.

Table 3.3: Out-of sample mean absolute forecast errors (*MAFEs*) of the Malaysian males and females arising from different methods: the independent, gender-coherence and developed-developing countries coherence models. The developed-developing countries coherence model outperformed the independent and gender coherence models for males (series 7) and females (series 5).

Series	Models			*MAFEs*		
	Mortality	**Fertility**	**Migration**	**Male**	**Female**	**Overall**
Independent model						
1	independent	independent	independent	6510	5400	5960
Gender coherence model						
2	gender	independent	gender	6390	5870	6130
Developed-developing countries coherence model						
3	developed	independent	developed	5690	5030	5360
4	developed10	independent	developed10	5510	4820	5170
5	developed20	independent	developed20	5640	4260	4950
6	developed	developed	developed	8560	6810	7690
7	developed10	developed10	developed10	5050	4320	4690
8	developed20	developed20	developed20	6210	5680	5950

major accuracy improvement in series 7 indicates that the Malaysian population is best forecast using the Australian 10-year lagged data for all demographic components: mortality, fertility and net international migration.

3.5.1.1 The accuracy of mortality and fertility models

In order to identify an appropriate accurate demographic component model, the accuracy of age-specific death rates (*ASDRs*) and age-specific fertility rates (*ASFRs*) was evaluated across different methods and summarised in Table 3.4 and Table 3.5. The net migration models are excluded from this evaluation as observed Malaysian net migration data are unavailable.

Table 3.4 shows that the gender-coherence mortality model outperforms the independent model for males, and vice versa for females. A broad comparison shows the developed10 model is the most accurate model, outperforming the independent and gender coherence models for males and performing best overall. Using this developed10 mortality model for population forecasts resulted in the most accurate population forecast for males and overall, as in Table 3.3. This would seem to indicate that an accurate mortality model plays an important role

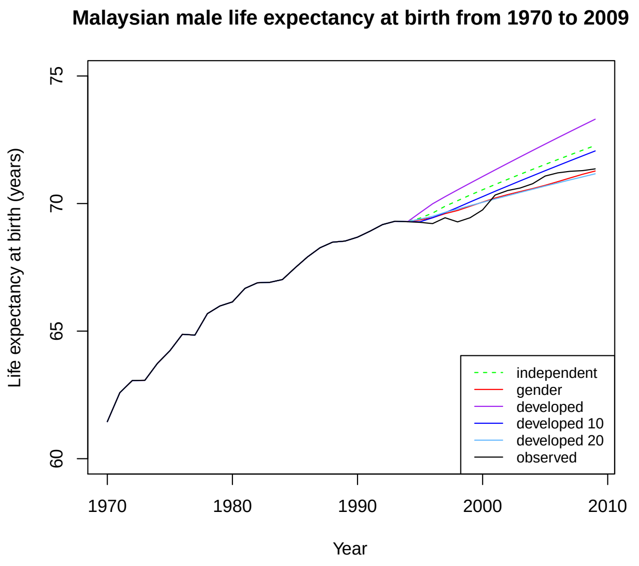
Table 3.4: Out-of sample mean absolute forecast errors (*MAFE*s) for Malaysian age-specific death rates (*ASDR*s) from the independent, gender-coherence and developed-developing countries coherence models for Malaysian males, females and overall. The developed10-developing countries coherence model was the most accurate model for male mortality while the independent model was the most accurate for female mortality. For overall, the the developed10-developing countries coherence model outperformed other models.

Series	**Mortality model**	***MAFE* male**	***MAFE* female**	***MAFE* overall**
1	independent	0.00104	0.00069	0.00087
2	gender	0.00081	0.00071	0.00076
3	developed	0.00171	0.00100	0.00136
4	developed10	0.00010	0.00122	0.00066
5	developed20	0.00084	0.00078	0.00081

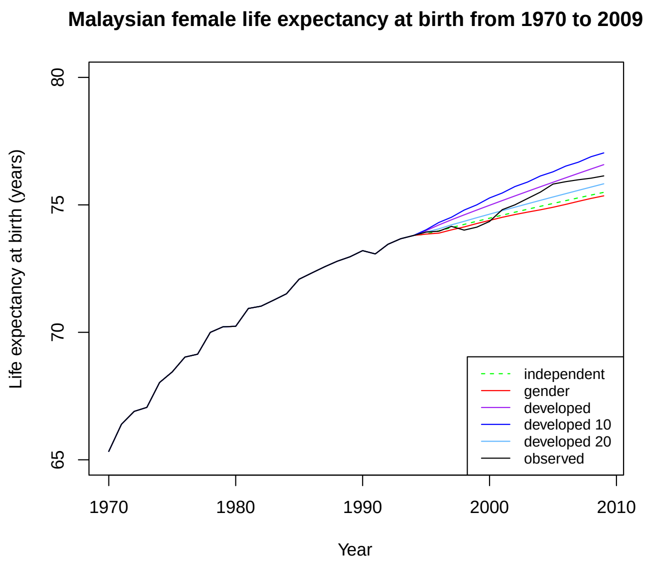
in producing accurate population forecasts.

Extra attention must be given when integrating data from different countries into the modelling. As can be seen in Table 3.4, the $ASDR$ forecast error of the developed model (series 3) is substantially higher than the rest of the models for males and overall. The reason for the high forecast error for this developed model is because during the estimation period (1970–1994) Australian males mortality declined at a faster rate than that of Australian females, which has resulted in a reduced the life expectancy gap. This trend, however, contradicts Malaysia where during that particular period male mortality decreased at a very slow rate, hence increasing the life expectancy gap between males and females. Therefore, using Australian male mortality as reference rates for Malaysian males jeopardises the accuracy of Malaysian male death rate forecasts. This problem also affected life expectancy at birth estimation. Figure 3.5 clearly shows that the developed model has significantly over estimated the Malaysian male life expectancy at birth. Nevertheless, this problem can be fixed using the 10-year lagged fitting period for Australia, which resulted in the develop10 model outperforming other models.

Turning to the forecast performance of fertility models, where Table 3.5 shows the developed model (no lagged Australian fertility) is the most accurate model for Malaysian fertility. This developed fertility model does not, however, con-



(a)



(b)

Figure 3.5: The observed and 15-year out-of-sample life expectancy at birth forecasts for (a) males and (b) females using different methods. Male life expectancy from the developed model is significantly higher than other methods. This forecast error can be reduced using the developed10 and developed 20 methods. For females, the developed method produces the most accurate life expectancy at birth forecast.

Table 3.5: Out-of sample mean absolute forecast errors (*MAFE*s) for Malaysian age-specific fertility rates (*ASFR*s) from the independent, gender-coherence and developed-developing countries coherence models. The developed-developing countries coherence model is the most accurate followed by the developed10-developing countries coherence model.

Series	**Fertility model**	***MAFE***
1	independent	0.00900
2	developed	0.00626
3	developed10	0.00725
4	developed20	0.00966

tribute to the most accurate population forecasts. The out-of sample population forecasts in Table 3.3 show that the most accurate female population forecast, series 5, used the independent model for fertility while the most accurate male population forecast, series 7, used the developed10 model. Thus, even though an accurate mortality model appears to affect the accuracy of population forecasts, an accurate fertility model does not necessarily seem to affect population forecast accuracy—or if it does, the impact will be minimal.

The complexity of fertility forecasting has been highlighted in the literature. Hyndman & Booth (2008) pointed out that fertility has proved difficult to forecast due to its structural changes over the years. Time series forecasting will produce long run fertility forecasts that converge to the sample mean. However, the actual rate of fertility may decline slower or faster than that of the sample mean (Lee & Tuljapurkar 1994). Thus, the fertility model is sometimes adjusted to use the most recently observed age-specific fertility rates as the model's baseline, rather than the average so that the forecasts begin from the most recent rates, hence capturing the recent pattern (Li et al. 2004). In addition to historical time series data, it should be noted that total fertility rate forecasts may also greatly influence by the economic fluctuation and public policies such as wage compensation and better access to childcare (Glowaki & Richmond 2007).

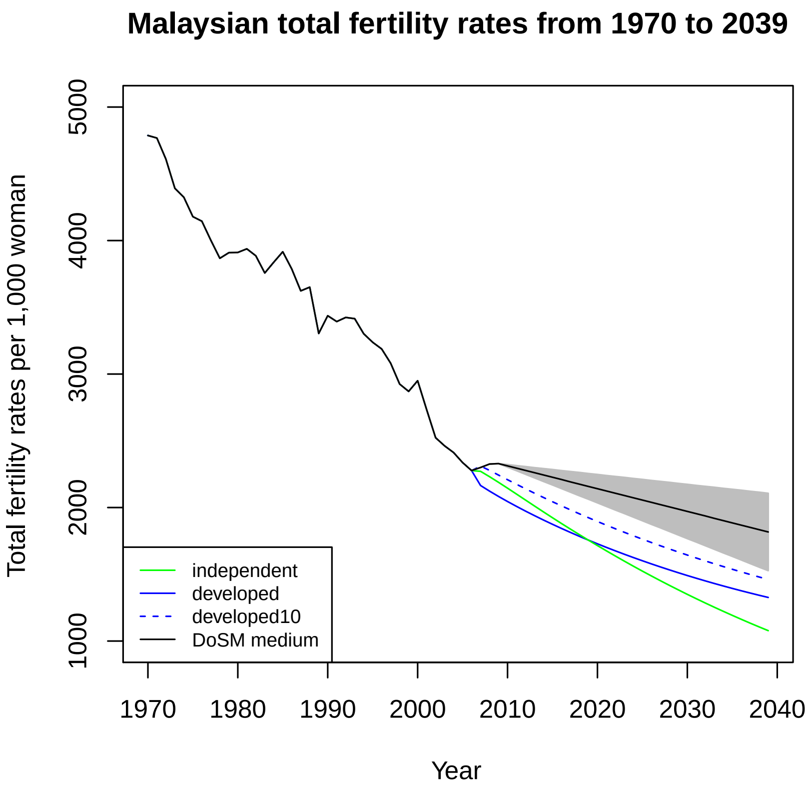
We find the long-term Malaysian fertility forecasts were improved using the developed-developing countries coherence model. Figure 3.6 shows how the long-term independent *TFR* forecast (green line) appears to be too low, reaching 1.08 in 2040. This value seems unreasonable as it is significantly lower than the *DoSM*'s low variant assumption, which is 1.5 for the same year. For the developed-developing countries forecast (blue line), we see that, by integrating the low fertility rates of Australia to the model, the Malaysian total fertility forecast was successfully constrained to be slightly higher than that of the independent forecasts. In addition, the long-term *TFR* forecast can be further improved using the developed10 fertility model (blue long dashed line). This developed10 fertility model successfully moves the *TFR* forecast upwards, closer to the *DoSM*'s low forecast values. Therefore, in performing long-term Malaysian age-specific population forecasts, the developed10 fertility model seems a better choice than that of the independent model.

It is noteworthy that Australia was chosen as a reference country to Malaysia due to two main reasons. First, the observed Malaysian total fertility rates are converging towards replacement ratio, which most developed nations including Australia, have experienced in previous years (Figure 3.3 depicts the changes in total fertility for Australia and Malaysia over time). These changes in fertility rates describe world vital rates are going towards low values. According to Corazziari et al. (2014), the convergence in vital rates has been associated with the theories of modernization, which assumed that developing countries would follow a path of economic and social progress similar to that of developed countries. The convergence theory however does not account for other drivers such as government policies and family cultural background, although they may influence the future estimates. Second, Australia is a developed country located in the same region as Malaysia— Southeast Asian, and share some common characteristics: both are multi-racial countries and members of Commonwealth nations.

3.5.2 Out-of-sample population forecast accuracy by ethnicity

We used the mean absolute percentage error (*MAPFE*) measurement to evaluate the out-of-sample sub-population forecasts for each ethnic group (Malay, Chinese and Indian) by gender.

For Chinese and Indians, the comparison between the independent model and the gender-coherence model showed consistent results with the total population forecasts, in which the gender-coherence model was more accurate than the independent model for males, and vice versa for females (refer to Table 3.6 and Table



(a)

Figure 3.6: The observed and long-term forecasts of total fertility rates per one thousand women up to year 2040. The forecast of the independent model is significantly lower than that of *DoSM* medium variant projection (black lines). The developed (blue lines) and developed10 models (blue dashed) produce forecast values that are closer to the *DoSM* projection range (grey shaded area).

Table 3.6: Out-of sample mean absolute percentage forecast errors (*MAPFE*) of the Chinese sub-population using the independent, gender-coherence and developed-developing countries coherence models for Chinese males and females. The developed-developing countries coherence model outperforms the independent and gender coherence models for males in forecast series 7 and females in forecast series 8.

Chinese						
Series	**Mortality model**	**Fertility model**	**Migration model**	***MAPFE* male**	***MAPFE* female**	***MAPFE* overall**
Independent model						
1	independent	independent	independent	6.19	5.77	5.98
Gender coherence model						
2	gender	independent	gender	5.24	5.80	5.52
Developed-developing countries coherence model						
3	developed	independent	developed	8.40	8.06	8.23
4	developed10	independent	developed10	7.82	6.12	6.97
5	developed20	independent	developed20	8.24	6.16	7.20
6	developed	developed	developed	10.95	7.23	9.09
7	developed10	developed10	developed10	4.10	4.95	4.53
8	developed20	developed20	developed20	5.35	3.90	4.63

Table 3.7: Out-of sample mean absolute percentage forecast errors (*MAPE*s) for the Malay population using the independent, gender-coherence and developed-developing countries coherence models. The developed-developing countries coherence model outperformed the independent and gender coherence models only for females (series 6). For males, the ethnic-coherence model significantly outperformed other models.

Malay						
Series	**Mortality model**	**Fertility model**	**Migration model**	***MAPFE* male**	***MAPFE* female**	***MAPFE* overall**
Independent model						
1	independent	independent	independent	4.22	4.25	4.24
Gender coherence model						
2	gender	independent	gender	3.65	3.65	3.65
Developed-developing countries coherence model						
3	developed	independent	developed	3.79	3.83	3.81
4	developed10	independent	developed10	3.53	3.80	3.67
5	developed20	independent	developed20	3.54	3.76	3.65
6	developed	developed	developed	3.25	3.38	3.32
7	developed10	developed10	developed10	3.36	3.42	3.39
8	developed20	developed20	developed20	4.39	4.96	4.68
Ethnic coherent model						
9	Chinese	independent	Chinese	3.18	3.79	3.49

3.8). However, for Malays, the gender-coherence model is better than independent for both genders (Table 3.7). In terms of overall accuracy, the gender-coherence model was more accurate than the independent model for all ethnic groups. When comparing across all methods, results showed that the developed-developing countries method outperformed the independent and gender coherent methods for the majority of the sub-populations, including Chinese males, Chinese females and Malay females.

From the Table 3.6 we can see that series 7 and 8 were the most accurate forecasts for Chinese males and females; series 7 is the best forecast overall. Series 7 indicated the Chinese group is best forecast using the developed10-developing countries coherence model for all demographic components, whereas series 8 adopted the developed20-developing countries coherence model for all components.

For the Malay groups we include another forecast (series 9) which applies the ethnic-coherence model for mortality and migration and the independent model for fertility. This ethnic-coherence method adopted the low mortality of the Chinese population as reference rates. Table 3.7 shows that the ethnic-coherence population model substantially improves the forecast accuracy of the Malay male population, outperforming the developed-developing countries and other models. On the other hand, this ethnic-coherence model did not improve the forecast accuracy of Malay females. Results indicated that series 6 yielding the most accurate forecasts for Malay females, resulting in all demographic components of this sub-population being forecast using the developed model.

Table 3.8 shows that the ethnic-coherence model also did not improve the accuracy of the Indian population forecast; it significantly underperforms other models. Indian females were best forecast using the independent population model (series 1) in which all demographic components were forecast using the independent model. Coherent models did not work better than that of the independent model for Indian females because Indian female mortality significantly decreased at a more rapid rate than other sub-populations including Australia females. Figure 3.2 (b) shows Indian female life expectancy at birth increased dramatically over the observed years. It surpassed Malay females and reduced life expectancy gap with Chinese and Australian females. On the other hand, Indian males were best forecast using the gender-coherence population model (series 2), which combined the gender coherence model for mortality and net migration, and the independent model for fertility.

Based on these out-of sample forecast errors for ethnic groups we conclude that the variation of demographic characteristics between ethnicities resulted in a variety of good population forecasting methods for each sub-population. We note that the developed-developing population forecasting models successfully improved the forecast accuracy of three out of the six ethnicity sub-populations. Our long-term sub-population forecasts in the next section acknowledge these differences and use the most accurate models as identified above.

3.6 Age-specific long-term population forecasts

3.6.1 Age-specific long-term population forecast by gender

In this section we report on the long-term age-specific Malaysian population forecasts to 2040 made for males and females. The methods that produced the most

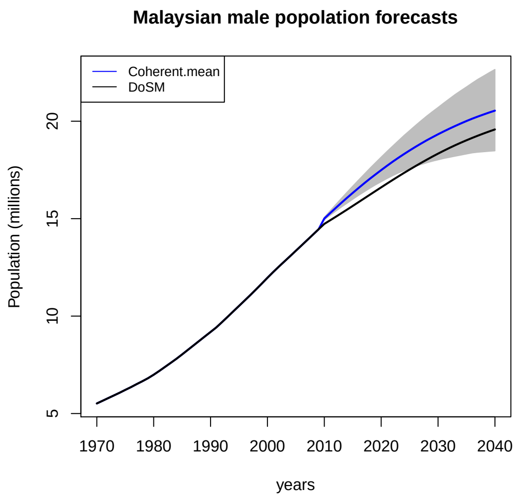
Table 3.8: Out-of sample mean absolute percentage forecast errors (*MAPE*s) for the Indian population using the independent, gender-coherence and developed-developing countries coherence models. The developed-developing countries coherence models underperformed the independent and gender coherence models for both males and females. For males the gender coherence model was the most accurate while for females the independent model was the most accurate.

Indian						
Series	**Mortality model**	**Fertility model**	**Migration model**	***MAPFE* male**	***MAPFE* female**	***MAPFE* overall**
Independent model						
1	independent	independent	independent	7.28	5.40	6.34
Gender coherence model						
2	gender	independent	gender	6.35	5.78	6.07
Developed-developing countries coherence model						
3	developed	independent	developed	11.71	5.94	8.83
4	developed10	independent	developed10	10.52	6.92	8.72
5	developed20	independent	developed20	13.57	20.64	17.11
6	developed	developed	developed	11.20	5.87	8.54
7	developed10	developed10	developed10	6.70	5.82	6.26
8	developed20	developed20	developed20	9.38	15.97	12.67
Ethnic coherence model						
9	Chinese	independent	Chinese	15.52	12.97	14.25

accurate out-of-sample forecasts for each sub-population, described in section 3.5.1, were used. It is notable, for the overall case, forecast series 7 had the least out-of-sample forecast error, and so this method is adopted for Malaysian male and female long-term forecasts. The method includes each of the demographic component rates (mortality rates, fertility rates and net-international migration numbers) in the same developed10-developing countries coherence model.

It is noteworthy that our forecast series provide better or at least as accurate as the Department of Statistics Malaysia (DoSM) population forecasts, which currently used three forecast variants, based on high, medium and low assumptions for fertility, mortality and net international migration. The DoSM's approach is purely deterministic in which statistical distributions are not incorporated in the forecasting model. In contrast, the stochastic population forecasting models used in this study estimate population size not as single number but as a whole range of probability distributions or prediction intervals. According to Keilman et al. (2002), the user of a probabilistic forecasts is better informed about the magnitude of the errors, and how these errors vary by age groups and gender.

The mean stochastic forecasts of total population, population by major age group and life expectancy at birth, together with the corresponding *DoSM*'s medium variant projection are presented in Figure 3.7. Figure 3.7a and 3.7b show the total population mean coherent forecasts are higher than the of official medium projection for males and females. This maybe due to our assumption that the mortality rates of Malaysian males and females will continue decreasing towards Australia mortality level, hence it is expected that Malaysian people will live longer. Figure 3.7c and 3.7d show the population forecasts of the working age group are substantially higher than *DoSM* projections, i.e., the mean coherent forecasts of children aged 0–14 are lower than the *DoSM* projections. Again, this may follow from our fertility model assuming Malaysian total fertility rates will continue decreasing towards the Australia's low fertility level. Our mean coherent forecasts indicate the life expectancy at birth for Malaysian males and females will continue increasing in the future and reach 76.70 years and 81.70 years in 2040, respectively. These estimates are, however, lower than the *DoSM*'s forecasts which the life expectancy at birth for males and females will be 78 years and 83 years in the same year. The *DoSM* assumes that the life expectancy at birth increases by 0.2 years constantly every year since 2010. On the other hand, our forecasts do not apply an assumption directly on the life expectancy at birth.



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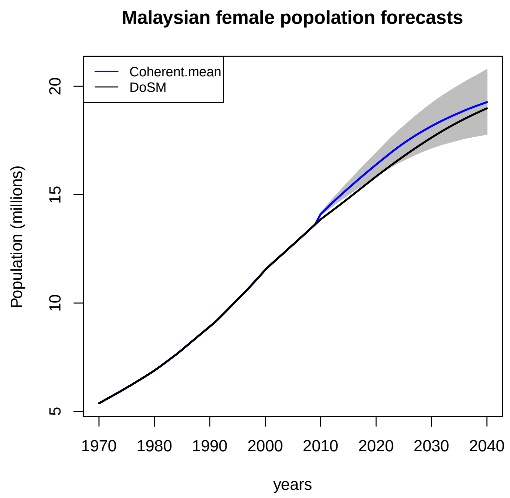

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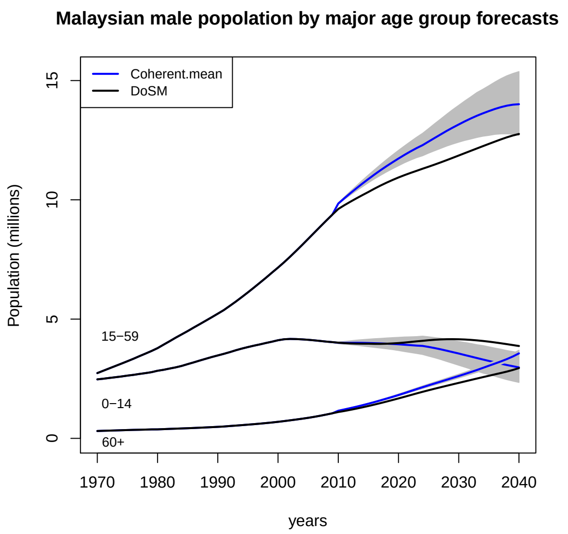

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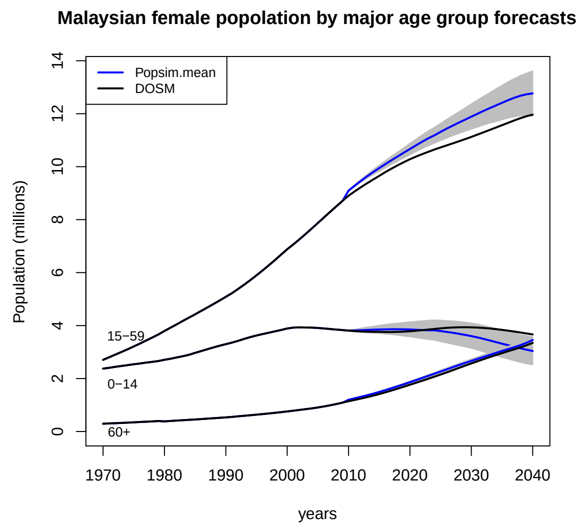


(d)

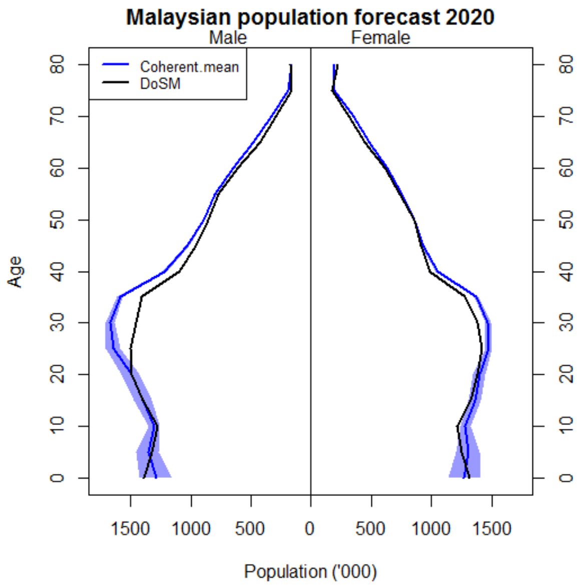
Figure 3.7: Observed and long-term forecasts of the Malaysia's total population and population by major age groups, for males and females. The mean coherent forecasts (`coherent.mean`) are presented as blue lines and its prediction intervals show as in the shaded region. These forecasts are compared with the *DoSM* medium variant in black line. The `coherent.mean` higher than the medium variant population projection (*DoSM*) for total population and working-age group for both genders. However, the mean coherent forecasts of children are lower than that of the *DoSM*.

Rather, the life expectancy at birth is calculated using the life table method which is based on the forecast values of mortality rates. This approach has resulted in our life expectancy at birth forecasts increasing on average 0.15 per year.

Complete age-specific Malaysian male and female population forecasts (in absolute numbers), together with the *DoSM* population projections, are attached in Appendix 3.B.1 and Appendix 3.B.2, respectively. Population ageing indicators such as the old-age dependency ratio, the percentage of older people (aged 60 and above) and life expectancy at birth, are calculated and appear in Appendix 3.B.3. In comparisons of each projection with the *DoSM*, our male population is expected to age at a more rapid pace due sustained low fertility and increasing life expectancy assumptions. For example, the percentage of mean coherent forecasts for elderly Malaysian males will reach 15% of the total population by 2034, five years before than that of the *DoSM*. On the other hand, the coherent population forecast of females reaching that 15% level by 2030, the same year as the *DoSM* projection. Furthermore, since the female population reaches the 15% level earlier than that of males, the forecast indicates a feminisation of ageing.

The Malaysian mean coherent forecasts of the old-age dependency ratios ($OADR$) are expected to double, from 12% to 25% and from 13% to 27% for males and females over the forecast years 2010–2040. One older person is likely to be dependent on the support of five working age people (20%) by 2030 for males and by 2024 for females. Nevertheless, the Malaysian old-age dependency ratio is still low compared to the oldest nation, Japan, whose ratio already reached 35% of the total population in 2010 and is forecast to increase to 74% by 2050 (United Nations 2011).

The Malaysian population pyramid forecasts by gender are given in Figure 3.8. There is not much different between the *DoSM* (black lines) and the mean coherent (blue lines) forecasts for 2020 apart from the coherent forecasts producing larger populations than the *DoSM* between ages 25 to 50 for males and between ages 24 to 40 for females. In 2030, coherent mean population forecasts are larger than the *DoSM* for people aged 15 to 75 and 10 to 50 for males and females, respectively. In addition, children aged 0 to 10 years in our mean coherent forecasts reduce more rapidly than the *DoSM* from 2020 to 2030 for both males and females. Consequently, these results change the 2030 pyramid shape to more rectangular than its shape in 2020, indicating the Malaysian population is rapidly ageing.



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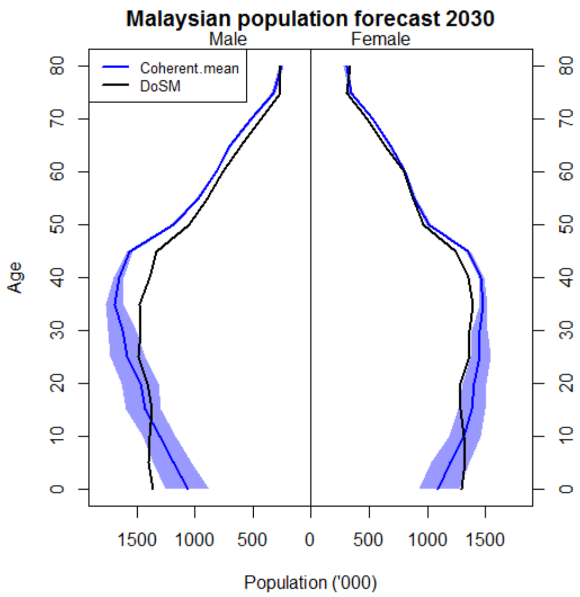

(b)

Figure 3.8: Malaysian long-term age-specific population forecasts by gender in absolute numbers. In year 2020 (a), the mean coherent forecasts (blue lines) are slightly larger than that of the medium variant projection from the *DoSM* (black lines) for both genders in most of the age groups. In year 2030 (b), the mean coherent forecasts are clearly larger than the *DoSM* with the number of children in the mean coherent forecasts substantially lower than the *DoSM*. There is significant change in the Malaysian population structure from approximately triangle in 2020 to a more rectangular shape in 2030, showing a clear sign of population ageing.

3.6.2 Age-specific long-term population forecast by ethnicity

The age-specific sub-population forecasts by ethnicity and its population ageing indicators are given in Appendices 3.B.4 to 3.B.12. Not a great deal of difference appears between our mean coherent forecasts and the medium variant of the *DoSM* projections for each ethnic group.

Population pyramids for each ethnic group, and by gender are presented in Figure 3.9. There is no significant difference between the *DoSM* (black lines) and the mean coherent methods (blue lines) for forecast years 2020 and 2030. We found that the medium variant of the official projection will fall within the coherent forecast high and low prediction intervals in the majority of sub-populations: Malay males, Chinese females, Indian males and Indian females.

The national ageing benchmark indicates Malaysia will become an aged country by 2030, with the elderly constituting 15% of the total population (Ambigga 2011, Forsyth & Chia 2009, Ong 2002). However this indicator does not reflect the ageing of ethnic groups. Each ethnicity has unique demographic component characteristics. The Malay elderly population is expected to grow at significantly slower rate than that of the Indian and Chinese elderly. This result reflects the higher observed mortality rates among Malays especially those in the accident age group. Based on our forecast, the Malay male elderly will only reach the aged population status (15% of Malay male population) in 2040 whereas for Malay females, the percentage of elderly attains only 13% of the Malay female population in the same year.

In contrast to Malays, the Chinese population is ageing rapidly. The Chinese have reached the aged population status in 2016 for both genders. In 2040, this percentage increases substantially to 23% of the total Chinese population. The rapid pace of population ageing among Chinese can be clearly seen in Figure 3.9c and 3.9d. The Chinese population pyramids appear to be more rectangular compared to the Malay's population pyramids in Figures 3.9a and 3.9b. These results are mainly due to he Chinese having the lowest mortality level among the three ethnic groups, as well as their total fertility rates having decreased and reached below the replacement ratio since 2006. The Indian population also ages at a more rapid pace than Malays but slower than Chinese. The Indian population is expected to reach 15% of its population by 2028 and 2022 for males and females. In 2040, the percentage of Indian male elderly will constitute 19% of the male Indian population and the Indian female elderly will represent 23% of the Indian female population.

Population forecasting by age, gender and ethnic groups is crucial in providing more detailed information about future population structure. In the context of long term care, different ethnic group may require different amounts or levels of care. For example, because the Chinese population will attain ageing status in 2016 and have a longer life expectancy at birth, extra resources are needed to cater for the demand for long term care from this group.

3.7 Discussion

In this paper, we developed independent and coherent stochastic age-specific population forecasts for Malaysia. Each of the demographic components—namely mortality rates, fertility rates and net international migration numbers—are forecast independently and coherently between sub-populations using the independent functional model and the product-ratio coherent model. In addition to gender coherence, we explored another type of coherency: developed-developing countries coherence.

There is no clear indication how sub-populations should be treated in the same group or coherently forecast between each other. Li & Lee (2005) suggested populations can be grouped together when they have similar socioeconomic conditions and close connections and geographic proximity. These criteria are usually met by genders in the same region. Nonetheless, the application of coherent models has been successfully extended to more than just between genders. Hyndman et al. (2013) treat coherency between states, Shang et al. (2013) and Li & Lee (2005) treat coherency between countries and Shair et al. (2015) treat coherency between ethnicity. One advantage of a coherent model over an independent model is that it will ensure the forecast of sub-populations in the same group maintains certain structural relationships—for example, male mortality remains proportionally higher than female mortality—continuing the observed patterns (Hyndman et al. 2013).

To the best of our knowledge the application of the product-ratio coherent model between developed and developing countries has not been documented in the literature before. This paper fills the gap by coherently forecasting the

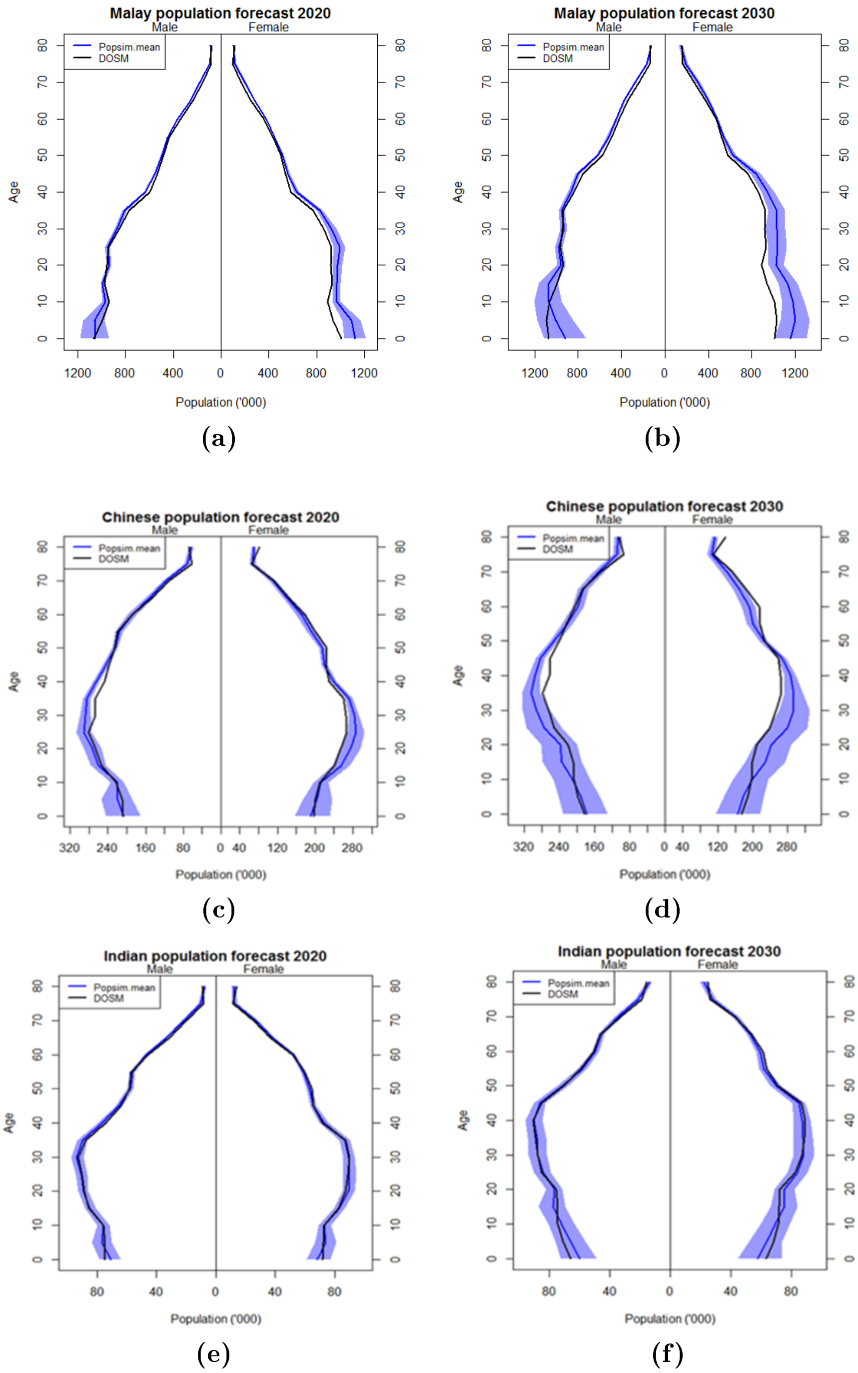

Figure 3.9: Malaysian long-term age-specific population forecasts by gender and ethnicity in absolute numbers. In 2020, there is no significant difference between the mean coherent forecasts (blue lines) and the *DoSM* medium variant projection (black lines) in all ethnic groups. However, in 2030, significant differences can be seen between these two forecasts for Malay females, Chinese males and Chinese females. The Chinese population is ageing more rapidly than that of the Malays and Indians, as evidenced by its more rectangular population structure.

demographic component rates of a developing country's sub-populations with a developed country's sub-populations. This type of coherency is motivated by global mortality and fertility convergence, that is, the mortality and fertility of developing countries are expected to continue decreasing towards the low levels that are currently experienced by most developed countries. Further, Li & Lee (2005), argue it is improper to prepare mortality forecasts for individual national populations in isolation from one another. Past data have also suggested that there is strong relationship, between developed and developing countries in that the mortality rates and fertility rates of the majority of developed countries are consistently lower to some degree than those of developing countries. Moreover, Shair et al. (2015) suggest the incorporation of a lower mortality, but same gender, sub-population in a coherent model is more accurate than a lower mortality, and opposite gender, sub-population. As a result, we combined the demographic component rates of Malaysian males with Australian males and Malaysian females with Australian females to forecast Malaysian males and female rates.

In order to forecast the age-specific population that accounted for all the three demographic components, the independent functional population forecasting framework from Hyndman & Booth (2008) was adopted. This method is preferable to other methods because the flexibility of the model allows different characteristics of the three demographic components through the use of the Box-Cox transformation. The functional independent model was proposed by Hyndman & Ullah (2007), which extended the original Lee & Carter (1992) model. This model allowed for more than one principal component variable compared to Lee & Carter (1992) which included only one variable of decomposition. The use of more than one component is crucial, especially when the first component explains only a low percentage of variation. The additional number of principal components leads to more accurate forecasts.

In this paper, Hyndman & Booth (2008)'s framework was extended to the case of fully coherent stochastic forecasting. The coherent stochastic population forecasting model adopted used the product-ratio model from Hyndman et al. (2013) to forecast Malaysian sub-populations' mortality, fertility and net migration. Our developed-developing coherence modelling employed Australian data as the reference country with lower mortality and fertility—possible extensions of this work include incorporating other countries' sub-populations with lower mortality and fertility, especially those within the same Asian region.

The out-of-sample population forecast errors reported in section 5 indicated the developed-developing countries coherence model worked well in forecasting Malaysian male and female demographic components. The model outperformed the independent and gender-coherence models for both genders. Nevertheless, although Australian demographic rates served as good reference rates for Malaysia, we found that careful attention must be paid as to how the mortality or fertility trends of both countries changed over time. For instance, when we used unlagged data in the developd-developing countries coherence model with all three demographic components we obtained the highest forecast errors for both males and females and significantly over estimated the life expectancy at birth for males. Such errors were due to an increasing mortality differential between Australian males and Malaysian males over the fitting period—the coherent model works best when the difference is constant. Indeed, the application of a lagged series of Australia data resulted in a substantial improvement in forecast accuracy over the no lagged data model. It is apparent that, although low reference mortality and fertility rates may be useful in forecasting Malaysian sub-populations, accurate population forecasts are achievable only through careful choice of the fitting period.

Our findings suggest the developed-developing countries coherence population models also worked well for three out of six Malaysian ethnic sub-populations: Chinese males, Chinese females, and Malay females. For the other ethnic sub-populations their unique demographic component characteristics render what is suitable for one group not suitable for another. Even though the developed-developing countries coherence model produced the most accurate forecasts for Malay females, it did not produce the same result for Malay males. For Malay males, it seems that Chinese male mortality is more suitable than that of Australian males to act as the reference mortality rates given that the ethnic coherence model outperformed the developed-developing countries model for Malay males.

Our findings support the view that an accurate mortality model plays a big role in producing accurate population forecasts—the mortality model that produced the most accurate $ASDR$ forecast eventually will also produce the most accurate population forecast. On the other hand, the impact of fertility modelling on the population forecast was less crucial as we found that the most accurate fertility model did not necessarily yield the most accurate population forecast. Although in this instance the accuracy of the fertility model was less important, careful attention must nevertheless be given to how the fertility structure may change in the future. That is, in addition to the observed time series pattern, experts' opinions and judgments about the future fertility trend are also important. For instance, although the independent model was used to produce the most accurate forecast for Malaysian females, this model produces linearly decreasing forecast values which are substantially lower than that of the low assumption of the official projection. The time series independent model was unable to predict such structural changes as they occur outside the estimation period. However, our results suggest that this problem can be minimised using the developed-developing countries coherence model. This model produces long-term *TFR* forecasts that are closer to the official projection range. Indeed, a useful future research task is to develop a fertility model for Malaysia which captures structural change over the years.

The results in this paper show that the net international migration of Malaysia can be modelled coherently with reference to the net international migration of Australia. We found that the most accurate out-of-sample Malaysian male and female forecasts used the developed10 and developed20 coherence models in forecasting Malaysian male and female net international migrants. Australian and Malaysian net international migration numbers can be coherently modelled for two reasons. First, both countries are receiving and sending out migration nations with the observed number of immigrants exceeding out migrant for working-age groups (Figure 3.4). Second, the Malaysian and Australian population is expected to continue ageing as a result of a decrease in mortality and fertility. Hence it is reasonable to conclude that these countries will open their doors to immigrants to avoid the labour shortages amongst the working-age population.

Applying the developed10-developing coherence model in forecasting the future Malaysian male and female population resulted in our mean coherent stochastic population forecasts ageing at more rapid rate than those of the *DoSM* medium variant population projections. For instance, in comparison with the *DoSM* our forecasts show that Malaysian older males aged 60 years and above will reach 15% of the male population five years earlier—in 2034. The forecasts of working age population is higher, while the number of children is lower than that of the *DoSM* projection. The forecast life expectancy at birth in 2040 is 81.7 years for females and 76.7 for males. This is equivalent to the life expectancy at birth of Australian females and males in 1998 and 2000, respectively. Although the out-of sample forecast evaluation indicated that the developed10-developing countries coherence population model outperformed other methods, it is impossible to say that the same model will be more accurate than that of the *DoSM* for these long-term population forecasts. Future work monitoring the performance of our long-term coherent population forecasts against that of the *DoSM* would be useful.

3.8 Conclusion

In this research we jointly forecast Malaysia's sub-populations with reference to Australian sub-populations using the developed-developing countries coherence model. The demographic component rates, including mortality rates, fertility rates and net-international migration numbers, of Malaysian males and females and Australian males and females were coherently forecast using the product-ratio method from Hyndman et al. (2013). The forecast values of each component were then combined using the cohort component method of population projection, to obtain age-specific Malaysian male and female forecasts.

Results showed that the developed-developing countries coherence model successfully out-performed the gender coherence model and the independent model for Malaysian males and Malaysian females. This result confirms Shair et al. (2015)'s findings that coherent models have the potential to be more accurate than independent models, provided an appropriate type of coherency is chosen. In this case we found that developed-developing countries coherence was better than gender coherence. In addition, the developed-developing countries coherence model produced the most accurate forecasts for three out of six Malaysian sub-populations by ethnicity and gender—for Chinese males, Chinese females and Malay females.

Nevertheless, careful attention must be given to choosing the fitting period for Australian mortality, given that the short-term accuracy of coherent models appear to be strongly influenced by the constant differential of mortality rates between sub-populations. That is, it was found that the developed-developing countries coherence with no lag estimation period for Australia mortality data produced the highest *ASDR* forecast errors for Malaysian males compared to other models and substantially over estimated the life expectancy at birth of Malaysian males. This error, however, reduced significantly when 10-year lagged data was used in the developed10-developing countries coherence model. Thus, Australian sub-populations can be good reference rates in forecasting Malaysian sub-populations, but careful attention must be paid how the structure of the demographic components of both countries change over time.

We leave to future work the exploration of using other countries, preferably low mortality and fertility countries, to determine the best reference rates for Malaysian sub-populations. The task of exploring for which countries Malaysian demographies could serve as a worthwhile reference, too, remains.

3.A Interpolation coefficients for the Karup-King four-term third-difference formula

Table A1: Subdivision of quinquennial group into fifths. Source: Bijak & Kupiszewska (2008)

	First group N_0		
	N_0	N_1	N_2
first fifth	+0.344	–0.208	+0.064
second fifth	+0.248	–0.056	+0.008
third fifth	+0.176	+0.048	–0.024
fourth fifth	+0.128	+0.104	–0.032
last fifth	+0.104	+0.112	–0.016
	Middle group N_i		
	N_{i-1}	N_i	N_{i+1}
first fifth	+0.064	+0.152	–0.016
second fifth	+0.008	+0.224	–0.032
third fifth	–0.024	+0.248	–0.024
fourth fifth	–0.032	+0.224	+0.008
last fifth	–0.016	+0.152	+0.064
	Last group N_k		
	N_{k-2}	N_{k-1}	N_k
first fifth	–0.016	+0.112	+0.104
second fifth	–0.032	+0.104	+0.128
third fifth	–0.024	+0.048	+0.176
fourth fifth	+0.008	–0.056	+0.248
last fifth	+0.064	–0.208	+0.344

3.B Malaysian age-specific population forecasts

3.B.1 Malaysia female population forecasts

	Old age (60 and above)				Working age (15-59)				Children (0-14)				Total (0-80)			
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi
2010	1,143,900	1,199,808	1,191,512	1,207,794	8,903,200	9,096,144	9,072,535	9,119,372	3,810,900	3,808,899	3,784,463	3,836,452	13,858,000	14,104,850	14,048,510	14,163,618
2011	1,192,100	1,255,722	1,242,915	1,268,315	9,068,900	9,282,479	9,243,208	9,321,501	3,791,300	3,813,657	3,762,298	3,865,498	14,052,300	14,351,859	14,248,420	14,455,314
2012	1,243,200	1,311,315	1,295,326	1,326,778	9,222,500	9,462,338	9,407,340	9,519,560	3,777,300	3,822,640	3,747,871	3,903,698	14,243,000	14,596,294	14,450,536	14,750,036
2013	1,296,700	1,368,912	1,350,212	1,387,594	9,371,200	9,632,088	9,558,537	9,707,614	3,768,700	3,834,368	3,729,758	3,941,183	14,436,600	14,835,368	14,638,506	15,036,390
2014	1,353,600	1,429,075	1,406,080	1,451,919	9,514,700	9,793,733	9,697,411	9,889,243	3,764,700	3,844,710	3,716,657	3,973,037	14,633,000	15,067,517	14,820,148	15,314,198
2015	1,414,800	1,494,024	1,468,450	1,519,609	9,652,600	9,948,734	9,828,877	10,060,890	3,764,100	3,851,426	3,699,937	4,006,425	14,831,500	15,294,184	14,997,264	15,586,924
2016	1,479,700	1,563,043	1,534,089	1,591,729	9,795,200	10,098,094	9,957,881	10,228,118	3,756,500	3,855,963	3,680,304	4,040,131	15,031,400	15,517,100	15,172,274	15,859,978
2017	1,548,100	1,635,075	1,602,184	1,666,951	9,927,800	10,244,013	10,083,393	10,394,526	3,756,300	3,861,668	3,661,075	4,071,475	15,232,200	15,740,756	15,346,652	16,132,951
2018	1,619,200	1,709,254	1,672,265	1,744,294	10,051,200	10,387,269	10,207,746	10,557,654	3,762,900	3,860,925	3,635,706	4,089,270	15,433,300	15,957,449	15,515,717	16,391,217
2019	1,692,300	1,784,999	1,745,812	1,822,558	10,170,700	10,527,709	10,330,009	10,716,351	3,771,300	3,858,537	3,606,426	4,115,507	15,634,300	16,171,244	15,682,247	16,654,416
2020	1,766,200	1,862,061	1,821,383	1,902,680	10,282,400	10,667,301	10,451,178	10,879,492	3,785,800	3,852,783	3,576,773	4,139,353	15,834,400	16,382,145	15,849,334	16,921,525
2021	1,841,300	1,940,947	1,898,084	1,985,299	10,381,200	10,807,437	10,572,265	11,039,274	3,805,300	3,842,185	3,544,050	4,160,878	16,027,800	16,590,569	16,014,399	17,185,450
2022	1,917,000	2,020,698	1,973,735	2,068,698	10,474,400	10,944,541	10,685,516	11,199,147	3,827,700	3,830,548	3,507,886	4,179,246	16,219,100	16,795,786	16,167,138	17,447,091
2023	1,993,700	2,101,868	2,050,011	2,153,366	10,562,500	11,072,449	10,793,705	11,350,479	3,851,400	3,823,519	3,476,135	4,199,708	16,407,600	16,997,836	16,319,852	17,703,553
2024	2,071,700	2,183,205	2,127,495	2,235,052	10,648,800	11,185,938	10,888,962	11,484,885	3,872,400	3,821,809	3,449,234	4,210,506	16,592,900	17,190,952	16,465,691	17,930,442
2025	2,151,500	2,265,076	2,204,876	2,320,457	10,726,800	11,316,156	10,990,305	11,638,231	3,896,000	3,793,469	3,393,871	4,200,937	16,774,300	17,374,701	16,589,052	18,159,625
2026	2,233,400	2,347,500	2,281,901	2,405,725	10,804,500	11,437,269	11,080,106	11,787,853	3,915,100	3,761,206	3,347,684	4,187,431	16,953,000	17,545,976	16,709,691	18,381,009
2027	2,317,200	2,430,030	2,362,212	2,491,838	10,882,100	11,553,458	11,172,656	11,933,999	3,928,500	3,728,299	3,296,439	4,176,933	17,127,800	17,711,787	16,831,307	18,602,770
2028	2,402,400	2,511,118	2,442,716	2,575,787	10,960,600	11,666,631	11,256,282	12,076,877	3,936,000	3,688,559	3,248,470	4,149,900	17,299,000	17,866,307	16,947,468	18,802,565
2029	2,487,300	2,589,853	2,517,562	2,657,804	11,041,000	11,776,667	11,338,048	12,225,204	3,937,900	3,647,652	3,195,566	4,127,920	17,466,200	18,014,173	17,051,177	19,010,928
2030	2,570,200	2,666,145	2,588,992	2,738,060	11,123,900	11,888,195	11,419,995	12,370,522	3,933,900	3,603,236	3,141,960	4,094,960	17,628,000	18,157,576	17,150,947	19,203,542
2031	2,651,500	2,742,396	2,667,467	2,819,420	11,210,800	11,997,057	11,494,167	12,514,577	3,924,400	3,554,107	3,079,677	4,055,786	17,786,700	18,293,559	17,241,311	19,389,782
2032	2,732,200	2,817,656	2,739,896	2,899,691	11,298,600	12,107,138	11,573,826	12,661,265	3,909,700	3,496,955	3,007,554	4,004,478	17,940,500	18,421,750	17,321,276	19,565,433
2033	2,810,900	2,893,685	2,810,999	2,980,325	11,387,200	12,210,367	11,645,134	12,794,308	3,890,100	3,438,535	2,933,641	3,951,569	18,088,200	18,542,587	17,389,774	19,726,203
2034	2,887,000	2,970,189	2,886,097	3,062,339	11,476,600	12,310,870	11,704,446	12,936,215	3,866,400	3,378,680	2,866,512	3,893,474	18,230,000	18,659,739	17,457,054	19,892,028
2035	2,961,000	3,043,852	2,956,052	3,140,962	11,566,600	12,411,534	11,772,396	13,071,800	3,839,000	3,315,999	2,796,343	3,826,024	18,366,600	18,771,386	17,524,791	20,038,786
2036	3,033,500	3,114,489	3,021,396	3,217,836	11,656,500	12,509,810	11,834,668	13,204,882	3,807,900	3,258,910	2,740,465	3,774,918	18,497,900	18,883,208	17,596,528	20,197,635
2037	3,104,100	3,185,909	3,087,903	3,293,061	11,746,100	12,601,564	11,884,948	13,326,479	3,774,300	3,198,650	2,672,290	3,723,767	18,624,500	18,986,122	17,645,141	20,343,307
2038	3,176,600	3,262,344	3,161,039	3,372,839	11,831,300	12,678,301	11,919,853	13,439,898	3,739,000	3,141,574	2,614,508	3,661,230	18,746,900	19,082,219	17,695,399	20,473,968
2039	3,257,300	3,350,936	3,245,501	3,465,742	11,905,600	12,734,385	11,931,919	13,533,031	3,702,400	3,088,318	2,561,330	3,624,613	18,865,300	19,173,639	17,738,749	20,623,386
2040	3,348,500	3,455,909	3,345,840	3,575,299	11,964,700	12,766,903	11,915,838	13,615,651	3,665,600	3,041,163	2,518,440	3,575,140	18,978,800	19,263,975	17,780,118	20,766,090

3.B.2 Malaysian male population forecasts

	Old age (60 and above)				Working age (15-59)				Children (0-14)				Total (0-80)			
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi
2010	1,104,700	1,158,132	1,152,787	1,164,029	9,615,000	9,843,764	9,816,690	9,870,106	4,011,100	4,004,762	3,975,520	4,036,781	14,730,800	15,006,657	14,944,998	15,070,916
2011	1,146,400	1,212,382	1,203,127	1,221,490	9,772,500	10,063,178	10,015,382	10,113,185	3,993,200	4,003,237	3,947,598	4,063,084	14,912,100	15,278,797	15,166,107	15,397,759
2012	1,195,300	1,268,051	1,255,520	1,280,330	9,918,300	10,275,399	10,201,627	10,352,489	3,980,200	4,003,513	3,925,735	4,087,980	15,093,800	15,546,962	15,382,881	15,720,798
2013	1,245,900	1,326,396	1,310,504	1,342,315	10,059,500	10,480,503	10,380,830	10,583,876	3,972,700	4,005,744	3,903,143	4,116,117	15,278,100	15,812,643	15,594,477	16,042,308
2014	1,299,400	1,387,734	1,368,781	1,407,402	10,196,200	10,679,482	10,549,206	10,813,579	3,969,300	4,003,814	3,874,235	4,136,909	15,464,900	16,071,030	15,792,222	16,357,890
2015	1,356,100	1,452,494	1,431,163	1,475,095	10,328,400	10,871,909	10,718,670	11,037,803	3,969,300	3,997,373	3,844,166	4,156,210	15,653,800	16,321,775	15,994,000	16,669,108
2016	1,415,500	1,520,420	1,496,162	1,545,826	10,466,600	11,058,440	10,877,786	11,256,846	3,962,000	3,989,630	3,815,866	4,174,501	15,844,100	16,568,490	16,189,813	16,977,173
2017	1,477,400	1,591,576	1,564,253	1,619,484	10,596,000	11,238,450	11,025,664	11,471,430	3,961,600	3,981,525	3,785,661	4,187,869	16,035,000	16,811,550	16,375,578	17,278,783
2018	1,541,400	1,664,685	1,633,930	1,695,753	10,717,100	11,409,449	11,170,311	11,679,342	3,967,700	3,971,344	3,755,909	4,206,027	16,226,200	17,045,478	16,560,149	17,581,123
2019	1,607,500	1,739,217	1,706,051	1,773,731	10,830,600	11,572,568	11,304,338	11,879,685	3,979,300	3,957,810	3,723,818	4,220,155	16,417,400	17,269,595	16,734,208	17,873,571
2020	1,674,500	1,816,533	1,779,590	1,855,221	10,937,400	11,731,482	11,429,678	12,072,837	3,994,900	3,943,237	3,684,737	4,233,033	16,606,800	17,491,252	16,894,004	18,161,090
2021	1,743,300	1,897,460	1,856,851	1,939,271	11,035,600	11,885,087	11,556,851	12,259,221	4,016,500	3,925,401	3,641,317	4,246,983	16,795,400	17,707,948	17,055,018	18,445,474
2022	1,813,000	1,980,267	1,935,204	2,025,146	11,127,600	12,031,056	11,667,460	12,442,002	4,040,900	3,906,692	3,600,804	4,253,769	16,981,500	17,918,016	17,203,467	18,720,916
2023	1,883,000	2,062,854	2,013,357	2,110,994	11,214,700	12,167,292	11,768,855	12,620,974	4,066,900	3,889,187	3,561,229	4,262,870	17,164,600	18,119,333	17,343,441	18,994,839
2024	1,951,200	2,144,341	2,091,529	2,196,006	11,304,300	12,291,649	11,849,184	12,787,281	4,088,500	3,875,892	3,518,220	4,283,639	17,344,000	18,311,883	17,458,933	19,266,926
2025	2,017,000	2,223,385	2,165,711	2,279,904	11,389,200	12,442,609	11,959,968	12,985,479	4,113,500	3,832,841	3,448,264	4,255,281	17,519,700	18,498,835	17,573,943	19,520,664
2026	2,081,100	2,301,337	2,238,449	2,362,137	11,477,100	12,593,018	12,059,226	13,190,019	4,133,700	3,785,097	3,382,561	4,224,846	17,691,900	18,679,452	17,680,236	19,777,001
2027	2,143,100	2,378,609	2,310,982	2,441,860	11,568,700	12,741,319	12,157,638	13,386,295	4,147,800	3,732,717	3,308,089	4,195,424	17,859,600	18,852,645	17,776,710	20,023,579
2028	2,204,400	2,456,194	2,384,300	2,524,999	11,663,400	12,889,183	12,255,708	13,585,783	4,156,000	3,674,892	3,225,420	4,154,459	18,023,800	19,020,270	17,865,428	20,265,240
2029	2,265,200	2,534,850	2,459,154	2,606,595	11,760,000	13,027,441	12,340,433	13,780,294	4,158,000	3,615,239	3,147,336	4,104,374	18,183,200	19,177,529	17,946,923	20,491,263
2030	2,325,800	2,614,300	2,532,933	2,688,891	11,857,600	13,159,416	12,418,892	13,960,099	4,154,000	3,556,877	3,066,510	4,060,709	18,337,400	19,330,592	18,018,335	20,709,700
2031	2,385,700	2,694,837	2,610,017	2,773,114	11,956,000	13,288,782	12,492,020	14,143,709	4,144,100	3,492,970	2,986,831	4,018,588	18,485,800	19,476,589	18,088,868	20,935,410
2032	2,446,400	2,777,838	2,687,631	2,862,458	12,054,000	13,410,125	12,551,569	14,315,151	4,128,700	3,430,915	2,907,323	3,977,349	18,629,100	19,618,879	18,146,524	21,154,958
2033	2,506,600	2,863,433	2,767,350	2,951,641	12,151,500	13,522,585	12,615,556	14,494,256	4,108,200	3,367,970	2,822,237	3,925,361	18,766,300	19,753,988	18,205,143	21,371,258
2034	2,565,300	2,953,583	2,852,625	3,046,591	12,248,800	13,624,551	12,668,733	14,634,077	4,083,200	3,306,586	2,740,264	3,888,826	18,897,300	19,884,720	18,261,623	21,569,494
2035	2,623,500	3,044,388	2,939,508	3,144,614	12,344,900	13,719,547	12,702,861	14,781,234	4,054,400	3,246,410	2,676,650	3,835,674	19,022,800	20,010,346	18,319,019	21,761,522
2036	2,681,900	3,133,674	3,023,561	3,240,386	12,439,700	13,808,731	12,746,160	14,936,453	4,021,700	3,187,215	2,605,529	3,784,316	19,143,300	20,129,620	18,375,250	21,961,155
2037	2,739,300	3,225,622	3,111,195	3,339,486	12,533,100	13,885,474	12,765,868	15,077,909	3,986,200	3,129,600	2,532,254	3,736,071	19,258,600	20,240,696	18,409,317	22,153,466
2038	2,800,100	3,324,453	3,202,846	3,442,994	12,621,200	13,947,286	12,768,146	15,200,307	3,948,800	3,073,411	2,462,023	3,678,956	19,370,100	20,345,150	18,433,015	22,322,258
2039	2,868,500	3,434,587	3,306,908	3,561,010	12,698,100	13,989,341	12,748,286	15,296,314	3,910,300	3,023,896	2,402,659	3,637,070	19,476,900	20,447,824	18,457,854	22,494,394
2040	2,946,700	3,562,236	3,424,835	3,694,655	12,760,700	14,008,306	12,708,655	15,374,819	3,871,600	2,972,807	2,345,632	3,589,249	19,579,000	20,543,349	18,479,123	22,658,723

3.B.3 Malaysian female (a) and male (b) population ageing indicators

	Old-age dependency ratio				% Old (60+)				Life expectancy at birth		
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	coherent.mean	coherent.lo	coherent.hi
2010	13%	13%	13%	13%	8%	9%	8%	8%	77.00	76.75	77.27
2011	13%	14%	13%	14%	8%	9%	9%	9%	77.19	76.88	77.53
2012	13%	14%	14%	14%	9%	9%	9%	9%	77.36	76.99	77.75
2013	14%	14%	14%	14%	9%	9%	9%	9%	77.53	77.12	77.95
2014	14%	15%	14%	15%	9%	9%	9%	9%	77.69	77.26	78.16
2015	15%	15%	15%	15%	10%	10%	10%	9%	77.86	77.36	78.39
2016	15%	15%	15%	16%	10%	10%	10%	10%	78.02	77.53	78.59
2017	16%	16%	16%	16%	10%	10%	10%	10%	78.18	77.61	78.73
2018	16%	16%	16%	17%	10%	11%	11%	10%	78.34	77.76	78.95
2019	17%	17%	17%	17%	11%	11%	11%	10%	78.51	77.90	79.19
2020	17%	17%	17%	17%	11%	11%	11%	11%	78.67	77.96	79.31
2021	18%	18%	18%	18%	11%	12%	12%	11%	78.83	78.10	79.54
2022	18%	18%	18%	18%	12%	12%	12%	11%	78.98	78.17	79.73
2023	19%	19%	19%	19%	12%	12%	13%	12%	79.14	78.32	79.89
2024	19%	20%	20%	19%	12%	13%	13%	12%	79.30	78.45	80.09
2025	20%	20%	20%	20%	13%	13%	13%	12%	79.46	78.63	80.23
2026	21%	21%	21%	20%	13%	13%	14%	12%	79.61	78.72	80.43
2027	21%	21%	21%	21%	14%	14%	14%	13%	79.77	78.89	80.56
2028	22%	22%	22%	21%	14%	14%	14%	13%	79.92	79.08	80.73
2029	23%	22%	22%	22%	14%	14%	15%	13%	80.07	79.15	80.87
2030	23%	22%	23%	22%	15%	15%	15%	13%	80.22	79.26	81.03
2031	24%	23%	23%	23%	15%	15%	15%	14%	80.38	79.42	81.20
2032	24%	23%	24%	23%	15%	15%	16%	14%	80.53	79.50	81.40
2033	25%	24%	24%	23%	16%	16%	16%	14%	80.68	79.67	81.50
2034	25%	24%	25%	24%	16%	16%	17%	15%	80.82	79.80	81.68
2035	26%	25%	25%	24%	16%	16%	17%	15%	80.97	79.86	81.81
2036	26%	25%	26%	24%	16%	16%	17%	15%	81.12	79.97	82.03
2037	26%	25%	26%	25%	17%	17%	18%	15%	81.26	80.09	82.25
2038	27%	26%	27%	25%	17%	17%	18%	15%	81.41	80.23	82.29
2039	27%	26%	27%	26%	17%	17%	18%	16%	81.56	80.37	82.53
2040	28%	27%	28%	26%	18%	18%	19%	16%	81.70	80.49	82.67

(a)

	Old-age dependency ratio				% Old (60+)				Life expectancy at birth		
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	coherent.mean	coherent.lo	coherent.hi
2010	11%	12%	12%	12%	7%	8%	8%	8%	71.46	71.26	71.66
2011	12%	12%	12%	12%	8%	8%	8%	8%	71.64	71.35	71.92
2012	12%	12%	12%	12%	8%	8%	8%	8%	71.84	71.51	72.21
2013	12%	13%	13%	13%	8%	8%	8%	8%	72.03	71.63	72.45
2014	13%	13%	13%	13%	8%	9%	9%	9%	72.23	71.79	72.69
2015	13%	13%	13%	13%	9%	9%	9%	9%	72.42	71.96	72.89
2016	14%	14%	14%	14%	9%	9%	9%	9%	72.61	72.15	73.15
2017	14%	14%	14%	14%	9%	9%	10%	9%	72.80	72.29	73.36
2018	14%	15%	15%	15%	9%	10%	10%	10%	72.99	72.44	73.59
2019	15%	15%	15%	15%	10%	10%	10%	10%	73.17	72.59	73.79
2020	15%	15%	16%	15%	10%	10%	11%	10%	73.35	72.75	73.98
2021	16%	16%	16%	16%	10%	11%	11%	11%	73.53	72.91	74.16
2022	16%	16%	17%	16%	11%	11%	11%	11%	73.71	73.06	74.38
2023	17%	17%	17%	17%	11%	11%	12%	11%	73.88	73.18	74.57
2024	17%	17%	18%	17%	11%	12%	12%	11%	74.06	73.37	74.75
2025	18%	18%	18%	18%	12%	12%	12%	12%	74.23	73.49	74.95
2026	18%	18%	19%	18%	12%	12%	13%	12%	74.41	73.69	75.15
2027	19%	19%	19%	18%	12%	13%	13%	12%	74.58	73.78	75.34
2028	19%	19%	19%	19%	12%	13%	13%	12%	74.75	73.91	75.59
2029	19%	19%	20%	19%	12%	13%	14%	13%	74.92	74.11	75.69
2030	20%	20%	20%	19%	13%	14%	14%	13%	75.08	74.25	75.89
2031	20%	20%	21%	20%	13%	14%	14%	13%	75.25	74.35	76.06
2032	20%	21%	21%	20%	13%	14%	15%	14%	75.41	74.49	76.23
2033	21%	21%	22%	20%	13%	14%	15%	14%	75.58	74.64	76.47
2034	21%	22%	23%	21%	14%	15%	16%	14%	75.74	74.79	76.61
2035	21%	22%	23%	21%	14%	15%	16%	14%	75.90	74.95	76.83
2036	22%	23%	24%	22%	14%	16%	16%	15%	76.06	75.04	76.97
2037	22%	23%	24%	22%	14%	16%	17%	15%	76.22	75.19	77.23
2038	22%	24%	25%	23%	14%	16%	17%	15%	76.38	75.28	77.36
2039	23%	25%	26%	23%	15%	17%	18%	16%	76.54	75.45	77.53
2040	23%	25%	27%	24%	15%	17%	19%	16%	76.70	75.60	77.63

(b)

3.B.4 Malaysian Malay female population forecasts

	Old age (60 and above)				Working age (15-59)				Children (0-14)				Total (0-80)			
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi
2010	648,000	681,984	671,687	691,795	5,370,200	5,505,090	5,477,250	5,531,166	2,743,300	2,765,844	2,745,097	2,785,118	8,761,500	8,952,918	8,894,034	9,008,079
2011	673,200	715,996	699,077	732,529	5,493,600	5,642,544	5,592,032	5,687,502	2,738,100	2,794,226	2,758,253	2,829,281	8,904,900	9,152,766	9,049,362	9,249,313
2012	699,800	750,508	728,609	772,419	5,611,600	5,781,521	5,710,502	5,847,062	2,737,800	2,828,355	2,775,552	2,881,820	9,049,200	9,360,385	9,214,662	9,501,301
2013	727,900	785,580	758,642	810,864	5,726,700	5,921,304	5,826,836	6,004,542	2,742,400	2,866,874	2,795,744	2,937,085	9,197,000	9,573,758	9,381,222	9,752,491
2014	758,200	824,181	793,169	853,551	5,838,500	6,062,851	5,943,993	6,165,642	2,750,500	2,910,030	2,819,993	3,000,712	9,347,200	9,797,062	9,557,154	10,019,905
2015	791,000	864,065	829,098	898,220	5,947,300	6,201,008	6,067,779	6,322,791	2,761,600	2,954,428	2,845,159	3,063,961	9,499,900	10,019,501	9,742,036	10,284,973
2016	826,100	906,048	867,489	942,272	6,060,400	6,336,503	6,184,434	6,479,635	2,768,200	2,996,980	2,869,732	3,122,750	9,654,700	10,239,531	9,921,655	10,544,656
2017	863,400	949,244	907,640	990,273	6,168,800	6,470,071	6,300,020	6,633,874	2,779,000	3,040,293	2,896,521	3,182,230	9,811,200	10,459,608	10,104,181	10,806,377
2018	902,500	993,340	949,058	1,036,832	6,270,900	6,599,954	6,409,259	6,788,726	2,795,500	3,083,419	2,923,123	3,246,226	9,968,900	10,676,712	10,281,440	11,071,784
2019	943,000	1,037,597	990,832	1,084,511	6,370,700	6,730,695	6,514,721	6,940,392	2,814,000	3,131,474	2,951,051	3,316,154	10,127,700	10,899,767	10,456,604	11,341,058
2020	984,000	1,082,069	1,033,820	1,130,084	6,465,900	6,859,201	6,616,869	7,093,922	2,836,400	3,180,929	2,978,380	3,384,880	10,286,300	11,122,199	10,629,068	11,608,885
2021	1,026,000	1,127,381	1,075,625	1,177,473	6,556,900	6,984,781	6,710,314	7,247,770	2,862,100	3,228,908	3,006,216	3,454,181	10,445,000	11,341,071	10,792,154	11,879,424
2022	1,069,000	1,172,408	1,117,105	1,227,627	6,644,300	7,110,390	6,804,046	7,394,032	2,889,800	3,279,737	3,039,045	3,528,183	10,603,100	11,562,535	10,960,196	12,149,843
2023	1,112,300	1,216,619	1,156,771	1,273,772	6,728,800	7,232,583	6,901,552	7,540,520	2,918,900	3,331,337	3,073,992	3,607,261	10,760,000	11,780,539	11,132,314	12,421,553
2024	1,156,500	1,261,281	1,197,873	1,321,548	6,813,800	7,350,571	6,991,442	7,685,445	2,944,800	3,388,741	3,113,791	3,677,729	10,915,100	12,000,592	11,303,106	12,684,722
2025	1,201,400	1,305,840	1,240,018	1,368,272	6,894,600	7,487,553	7,091,765	7,856,969	2,971,900	3,427,878	3,138,018	3,736,850	11,067,900	12,221,270	11,469,801	12,962,091
2026	1,247,300	1,349,678	1,280,666	1,416,224	6,976,500	7,621,756	7,185,885	8,023,706	2,995,200	3,457,197	3,150,628	3,785,740	11,219,000	12,428,631	11,617,179	13,225,671
2027	1,294,400	1,394,884	1,321,336	1,467,432	7,059,900	7,763,485	7,293,386	8,201,559	3,013,900	3,483,463	3,160,218	3,829,126	11,368,200	12,641,833	11,774,940	13,498,117
2028	1,342,000	1,438,945	1,358,823	1,514,907	7,145,100	7,906,060	7,403,632	8,381,863	3,027,600	3,503,170	3,167,550	3,867,291	11,514,700	12,848,175	11,930,006	13,764,061
2029	1,390,000	1,481,330	1,393,726	1,563,603	7,232,400	8,050,218	7,500,634	8,561,130	3,036,600	3,517,867	3,165,853	3,893,997	11,659,000	13,049,415	12,060,212	14,018,730
2030	1,437,100	1,522,409	1,429,094	1,607,954	7,322,200	8,200,169	7,618,244	8,750,792	3,040,700	3,529,986	3,157,467	3,922,823	11,800,000	13,252,564	12,204,805	14,281,569
2031	1,483,500	1,562,853	1,464,975	1,654,210	7,413,500	8,350,740	7,735,990	8,938,636	3,040,100	3,541,256	3,151,842	3,951,870	11,937,100	13,454,849	12,352,806	14,544,717
2032	1,530,400	1,602,783	1,499,558	1,701,834	7,505,800	8,503,878	7,847,815	9,136,123	3,035,000	3,551,362	3,144,601	3,983,204	12,071,200	13,658,023	12,491,973	14,821,160
2033	1,576,700	1,640,730	1,528,467	1,747,466	7,599,400	8,651,461	7,957,085	9,331,761	3,025,900	3,557,499	3,129,942	4,001,864	12,202,000	13,849,691	12,615,494	15,081,091
2034	1,621,700	1,679,077	1,560,576	1,792,974	7,694,000	8,799,620	8,067,489	9,523,772	3,013,100	3,560,639	3,117,900	4,027,327	12,328,800	14,039,336	12,745,964	15,344,074
2035	1,665,400	1,715,544	1,589,885	1,836,245	7,789,300	8,951,268	8,168,941	9,722,478	2,997,200	3,559,522	3,096,763	4,048,268	12,451,900	14,226,334	12,855,589	15,606,990
2036	1,708,500	1,749,582	1,616,798	1,874,474	7,884,000	9,105,061	8,265,901	9,914,892	2,978,200	3,561,883	3,078,958	4,066,198	12,570,700	14,416,526	12,961,656	15,855,564
2037	1,750,500	1,783,909	1,636,843	1,915,913	7,977,900	9,257,993	8,379,872	10,116,849	2,956,800	3,562,588	3,062,718	4,088,723	12,685,200	14,604,490	13,079,434	16,121,484
2038	1,793,900	1,820,526	1,663,029	1,962,855	8,068,800	9,401,156	8,481,681	10,312,369	2,934,000	3,560,828	3,042,542	4,112,054	12,796,700	14,782,509	13,187,252	16,387,278
2039	1,842,500	1,864,293	1,691,400	2,013,364	8,151,600	9,540,626	8,571,840	10,497,330	2,910,100	3,559,099	3,020,496	4,129,157	12,904,200	14,964,019	13,283,737	16,639,851
2040	1,898,500	1,917,062	1,732,020	2,075,034	8,223,900	9,670,888	8,653,917	10,676,736	2,885,900	3,561,880	2,997,383	4,145,687	13,008,300	15,149,830	13,383,320	16,897,457

3.B.5 Malaysian Malay male population forecasts

	Old age (60 and above)				Working age (15-59)				Children (0-14)				Total (0-80)			
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi
2010	594,800	621,028	610,934	630,182	5,437,800	5,564,851	5,530,652	5,593,260	2,882,500	2,898,936	2,873,664	2,922,898	8,915,100	9,084,816	9,015,250	9,146,340
2011	617,700	646,761	631,619	660,675	5,559,800	5,685,222	5,625,929	5,733,012	2,880,000	2,916,303	2,872,209	2,957,445	9,057,500	9,248,287	9,129,756	9,351,132
2012	643,900	673,768	654,563	691,379	5,676,000	5,805,306	5,732,436	5,867,708	2,881,900	2,936,015	2,872,258	2,994,211	9,201,800	9,415,089	9,259,257	9,553,299
2013	671,400	702,592	681,986	722,913	5,789,800	5,920,525	5,841,925	5,991,380	2,888,200	2,956,179	2,877,195	3,034,281	9,349,400	9,579,296	9,401,106	9,748,574
2014	700,500	734,169	710,453	757,727	5,901,100	6,034,463	5,942,547	6,116,138	2,897,800	2,979,437	2,878,736	3,081,249	9,499,400	9,748,069	9,531,736	9,955,114
2015	731,400	768,914	741,987	794,976	6,009,800	6,149,410	6,050,919	6,240,058	2,910,800	2,999,739	2,881,440	3,122,441	9,652,000	9,918,063	9,674,347	10,157,475
2016	763,800	805,413	775,514	835,003	6,124,100	6,263,042	6,153,361	6,361,028	2,918,900	3,018,737	2,877,627	3,162,118	9,806,800	10,087,191	9,806,502	10,358,148
2017	797,400	844,446	811,708	875,477	6,233,900	6,376,803	6,260,607	6,483,849	2,931,600	3,035,488	2,869,248	3,211,146	9,962,900	10,256,737	9,941,563	10,570,471
2018	832,100	884,782	848,528	917,800	6,338,200	6,483,275	6,360,268	6,600,494	2,949,800	3,050,947	2,865,704	3,246,221	10,120,100	10,419,004	10,074,499	10,764,514
2019	868,300	926,769	889,669	962,408	6,437,800	6,594,057	6,464,587	6,719,519	2,972,300	3,067,289	2,861,162	3,291,693	10,278,400	10,588,115	10,215,418	10,973,620
2020	905,300	969,823	930,776	1,007,326	6,533,800	6,697,153	6,556,708	6,832,080	2,997,300	3,079,424	2,848,205	3,328,934	10,436,400	10,746,401	10,335,689	11,168,340
2021	943,400	1,014,541	973,540	1,053,007	6,624,700	6,794,219	6,640,157	6,938,471	3,026,700	3,090,799	2,832,860	3,372,462	10,594,800	10,899,559	10,446,558	11,363,939
2022	982,500	1,060,034	1,017,067	1,101,346	6,711,000	6,888,841	6,725,456	7,044,782	3,058,300	3,101,940	2,817,083	3,412,609	10,751,800	11,050,814	10,559,606	11,558,738
2023	1,021,800	1,105,277	1,063,013	1,148,691	6,794,700	6,979,913	6,805,624	7,145,084	3,091,200	3,116,351	2,808,105	3,457,223	10,907,700	11,201,541	10,676,742	11,750,998
2024	1,060,200	1,148,174	1,105,937	1,193,504	6,882,500	7,061,399	6,878,047	7,236,056	3,118,900	3,133,182	2,795,504	3,501,580	11,061,600	11,342,756	10,779,488	11,931,139
2025	1,097,300	1,189,124	1,141,838	1,236,334	6,968,200	7,164,514	6,961,459	7,356,190	3,147,500	3,127,047	2,765,303	3,515,291	11,213,000	11,480,686	10,868,600	12,107,815
2026	1,133,900	1,229,247	1,180,109	1,279,312	7,056,700	7,268,156	7,048,288	7,476,277	3,172,400	3,115,039	2,725,775	3,523,186	11,363,000	11,612,441	10,954,172	12,278,775
2027	1,169,100	1,269,672	1,218,148	1,319,712	7,148,300	7,375,058	7,139,542	7,602,182	3,192,200	3,097,040	2,689,063	3,532,672	11,509,600	11,741,770	11,046,753	12,454,566
2028	1,203,700	1,310,250	1,257,736	1,361,053	7,243,100	7,486,568	7,234,642	7,730,454	3,207,000	3,071,214	2,642,384	3,527,255	11,653,800	11,868,032	11,134,762	12,618,762
2029	1,238,100	1,351,148	1,296,497	1,403,954	7,340,300	7,592,692	7,321,848	7,864,003	3,216,600	3,034,099	2,581,283	3,514,043	11,795,000	11,977,939	11,199,627	12,782,000
2030	1,271,800	1,393,185	1,335,709	1,448,013	7,438,600	7,702,939	7,410,092	8,002,062	3,220,700	2,994,879	2,519,214	3,491,268	11,931,100	12,091,003	11,265,015	12,941,343
2031	1,304,900	1,433,290	1,373,038	1,490,029	7,537,500	7,808,813	7,492,844	8,133,447	3,219,800	2,947,774	2,455,105	3,459,999	12,062,200	12,189,876	11,320,986	13,083,476
2032	1,338,100	1,473,625	1,408,141	1,535,482	7,636,300	7,912,282	7,568,377	8,270,858	3,213,800	2,894,468	2,383,574	3,420,124	12,188,200	12,280,375	11,360,092	13,226,464
2033	1,370,700	1,514,189	1,444,829	1,580,306	7,735,100	8,011,029	7,641,460	8,391,516	3,203,100	2,830,872	2,312,529	3,370,132	12,308,900	12,356,090	11,398,819	13,341,954
2034	1,402,400	1,555,359	1,483,448	1,624,378	7,833,500	8,104,794	7,712,399	8,511,052	3,188,500	2,758,950	2,228,909	3,310,717	12,424,400	12,419,102	11,424,755	13,446,147
2035	1,433,200	1,594,715	1,521,502	1,669,401	7,931,500	8,190,441	7,765,188	8,624,694	3,170,400	2,676,765	2,135,557	3,240,704	12,535,100	12,461,921	11,422,246	13,534,799
2036	1,464,100	1,633,367	1,557,888	1,711,127	8,028,100	8,281,437	7,829,286	8,742,849	3,149,100	2,586,658	2,046,739	3,159,210	12,641,300	12,501,462	11,433,914	13,613,186
2037	1,494,300	1,672,178	1,589,391	1,754,446	8,123,400	8,356,580	7,871,454	8,849,049	3,125,300	2,485,106	1,935,081	3,067,766	12,743,000	12,513,864	11,395,927	13,671,260
2038	1,526,500	1,716,034	1,629,706	1,803,832	8,214,500	8,431,779	7,914,852	8,967,687	3,099,800	2,371,832	1,818,359	2,964,403	12,840,800	12,519,645	11,362,917	13,735,921
2039	1,563,200	1,767,038	1,679,593	1,859,763	8,298,500	8,496,381	7,943,804	9,059,898	3,073,200	2,250,321	1,691,094	2,853,581	12,934,900	12,513,739	11,314,491	13,773,242
2040	1,605,800	1,826,573	1,733,725	1,918,872	8,372,000	8,554,041	7,962,446	9,155,216	3,046,300	2,122,118	1,558,598	2,733,523	13,024,100	12,502,732	11,254,768	13,807,611

3.B.6 Malaysian Malay female (a) and male (b) population ageing indicators

	Old-age dependency ratio				% Old (60+)				Life expectancy at birth		
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	coherent.mean	coherent.lo	coherent.hi
2010	12%	12%	12%	13%	7%	8%	8%	7%	73.57	73.35	73.79
2011	12%	13%	13%	13%	8%	8%	8%	8%	73.62	73.29	73.89
2012	12%	13%	13%	13%	8%	8%	8%	8%	73.77	73.38	74.08
2013	13%	13%	13%	14%	8%	8%	8%	8%	73.96	73.53	74.35
2014	13%	14%	13%	14%	8%	8%	8%	8%	74.12	73.59	74.57
2015	13%	14%	14%	14%	8%	9%	9%	8%	74.27	73.73	74.76
2016	14%	14%	14%	15%	9%	9%	9%	8%	74.42	73.83	75.00
2017	14%	15%	14%	15%	9%	9%	9%	8%	74.56	73.94	75.18
2018	14%	15%	15%	15%	9%	9%	9%	9%	74.70	74.01	75.34
2019	15%	15%	15%	16%	9%	10%	9%	9%	74.84	74.13	75.49
2020	15%	16%	16%	16%	10%	10%	10%	9%	74.98	74.25	75.65
2021	16%	16%	16%	16%	10%	10%	10%	9%	75.11	74.37	75.77
2022	16%	16%	16%	17%	10%	10%	10%	9%	75.24	74.48	75.91
2023	17%	17%	17%	17%	10%	10%	10%	9%	75.37	74.58	76.06
2024	17%	17%	17%	17%	11%	11%	11%	9%	75.50	74.70	76.25
2025	17%	17%	17%	17%	11%	11%	11%	10%	75.62	74.78	76.36
2026	18%	18%	18%	18%	11%	11%	11%	10%	75.74	74.89	76.49
2027	18%	18%	18%	18%	11%	11%	11%	10%	75.86	75.02	76.63
2028	19%	18%	18%	18%	12%	11%	11%	10%	75.98	75.13	76.74
2029	19%	18%	19%	18%	12%	11%	12%	10%	76.10	75.30	76.89
2030	20%	19%	19%	18%	12%	11%	12%	10%	76.21	75.29	77.01
2031	20%	19%	19%	19%	12%	12%	12%	10%	76.33	75.44	77.13
2032	20%	19%	19%	19%	13%	12%	12%	10%	76.45	75.57	77.28
2033	21%	19%	19%	19%	13%	12%	12%	10%	76.56	75.63	77.41
2034	21%	19%	19%	19%	13%	12%	12%	10%	76.68	75.71	77.52
2035	21%	19%	19%	19%	13%	12%	12%	10%	76.79	75.87	77.62
2036	22%	19%	20%	19%	14%	12%	12%	10%	76.91	75.95	77.75
2037	22%	19%	20%	19%	14%	12%	13%	10%	77.02	76.08	77.87
2038	22%	19%	20%	19%	14%	12%	13%	10%	77.13	76.24	77.99
2039	23%	20%	20%	19%	14%	12%	13%	10%	77.24	76.36	78.09
2040	23%	20%	20%	19%	15%	13%	13%	10%	77.36	76.36	78.25

(c)

	Old-age dependency ratio				% Old (60+)				Life expectancy at birth		
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	coherent.mean	coherent.lo	coherent.hi
2010	11%	11%	11%	11%	7%	7%	7%	7%	70.11	69.85	70.33
2011	11%	11%	11%	12%	7%	7%	7%	7%	70.33	70.00	70.63
2012	11%	12%	11%	12%	7%	7%	7%	7%	70.62	70.23	71.02
2013	12%	12%	12%	12%	7%	7%	7%	7%	70.92	70.47	71.40
2014	12%	12%	12%	12%	7%	8%	7%	8%	71.17	70.63	71.70
2015	12%	13%	12%	13%	8%	8%	8%	8%	71.40	70.83	71.98
2016	12%	13%	13%	13%	8%	8%	8%	8%	71.60	70.99	72.19
2017	13%	13%	13%	14%	8%	8%	8%	8%	71.79	71.16	72.46
2018	13%	14%	13%	14%	8%	8%	8%	9%	71.97	71.29	72.64
2019	13%	14%	14%	14%	8%	9%	9%	9%	72.15	71.46	72.85
2020	14%	14%	14%	15%	9%	9%	9%	9%	72.32	71.55	73.04
2021	14%	15%	15%	15%	9%	9%	9%	9%	72.50	71.72	73.26
2022	15%	15%	15%	16%	9%	10%	10%	10%	72.67	71.88	73.46
2023	15%	16%	16%	16%	9%	10%	10%	10%	72.84	72.02	73.67
2024	15%	16%	16%	16%	10%	10%	10%	10%	73.01	72.15	73.86
2025	16%	17%	16%	17%	10%	10%	11%	10%	73.18	72.32	74.00
2026	16%	17%	17%	17%	10%	11%	11%	10%	73.35	72.45	74.22
2027	16%	17%	17%	17%	10%	11%	11%	11%	73.51	72.60	74.34
2028	17%	18%	17%	18%	10%	11%	11%	11%	73.67	72.74	74.59
2029	17%	18%	18%	18%	10%	11%	12%	11%	73.83	72.90	74.68
2030	17%	18%	18%	18%	11%	12%	12%	11%	73.99	73.10	74.97
2031	17%	18%	18%	18%	11%	12%	12%	11%	74.14	73.24	75.03
2032	18%	19%	19%	19%	11%	12%	12%	12%	74.30	73.34	75.15
2033	18%	19%	19%	19%	11%	12%	13%	12%	74.45	73.51	75.35
2034	18%	19%	19%	19%	11%	13%	13%	12%	74.59	73.64	75.52
2035	18%	19%	20%	19%	11%	13%	13%	12%	74.74	73.83	75.64
2036	18%	20%	20%	20%	12%	13%	14%	13%	74.89	73.92	75.81
2037	18%	20%	20%	20%	12%	13%	14%	13%	75.03	74.13	75.93
2038	19%	20%	21%	20%	12%	14%	14%	13%	75.17	74.20	76.09
2039	19%	21%	21%	21%	12%	14%	15%	14%	75.31	74.32	76.23
2040	19%	21%	22%	21%	12%	15%	15%	14%	75.45	74.44	76.37

(d)

3.B.7 Malaysian Indian female population forecasts

	Old age (60 and above)				Working age (15-59)				Children (0-14)				Total (0-80)			
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi
2010	80,500	84,462	82,748	86,125	634,500	643,378	638,731	647,879	243,700	241,271	238,596	244,124	958,700	969,111	960,075	978,128
2011	84,500	88,577	85,864	91,176	644,000	651,777	643,965	659,221	240,200	238,639	233,837	243,745	968,700	978,993	963,667	994,142
2012	89,300	93,184	89,749	96,477	652,500	659,656	648,932	669,724	236,800	235,930	229,696	242,936	978,600	988,769	968,378	1,009,137
2013	94,200	98,018	93,786	101,938	660,700	666,793	653,581	679,586	233,800	233,253	224,913	241,931	988,700	998,064	972,280	1,023,455
2014	99,500	103,287	98,823	107,663	668,400	673,215	657,621	688,656	230,800	230,492	220,545	240,713	998,700	1,006,994	976,988	1,037,032
2015	105,400	109,151	104,110	114,002	674,900	678,992	661,210	696,576	228,200	227,778	216,701	239,549	1,008,500	1,015,921	982,021	1,050,127
2016	111,500	115,445	110,061	120,866	681,400	683,996	664,047	703,807	225,300	224,827	212,734	238,049	1,018,200	1,024,268	986,842	1,062,722
2017	118,200	122,041	116,157	127,787	686,900	688,587	667,010	710,565	222,800	222,010	208,401	236,912	1,027,900	1,032,638	991,567	1,075,264
2018	125,100	128,692	122,426	134,879	691,800	692,778	669,297	717,219	220,700	219,601	204,187	236,221	1,037,600	1,041,072	995,911	1,088,320
2019	132,300	135,327	128,762	142,189	696,300	696,447	670,824	722,276	218,400	217,278	200,538	235,421	1,047,000	1,049,051	1,000,124	1,099,886
2020	139,500	142,192	134,924	149,649	699,600	700,005	671,939	728,257	216,800	215,135	196,630	235,169	1,055,900	1,057,333	1,003,493	1,113,075
2021	146,600	148,884	141,545	156,421	702,300	702,782	672,432	732,685	215,900	213,109	192,737	234,507	1,064,800	1,064,775	1,006,714	1,123,612
2022	153,600	155,725	148,188	163,568	704,500	704,791	672,714	736,228	215,000	211,353	189,822	234,636	1,073,100	1,071,868	1,010,723	1,134,432
2023	160,900	162,484	154,579	170,557	706,500	705,924	671,769	739,894	214,100	209,860	186,377	235,400	1,081,500	1,078,267	1,012,726	1,145,850
2024	168,000	168,955	160,502	177,399	708,100	706,764	670,589	743,216	213,100	208,998	183,069	236,258	1,089,200	1,084,717	1,014,160	1,156,873
2025	175,300	175,424	166,429	183,861	709,300	709,061	670,554	748,321	212,400	206,251	178,748	234,567	1,097,000	1,090,736	1,015,731	1,166,748
2026	182,400	181,888	172,019	191,137	710,400	710,692	670,373	752,051	211,200	203,494	174,593	232,684	1,104,000	1,096,074	1,016,984	1,175,872
2027	189,600	188,145	177,880	197,997	711,500	712,417	669,553	755,504	209,800	200,493	170,328	231,224	1,110,900	1,101,055	1,017,760	1,184,725
2028	196,400	194,168	183,491	204,218	712,600	713,836	668,506	759,094	208,000	197,434	166,170	229,373	1,117,000	1,105,438	1,018,167	1,192,684
2029	203,300	199,973	188,957	210,676	714,000	715,269	667,240	763,067	205,800	194,743	161,567	227,875	1,123,100	1,109,985	1,017,763	1,201,619
2030	209,700	205,506	194,534	216,548	715,200	716,319	664,496	767,335	203,500	191,775	156,872	227,011	1,128,400	1,113,601	1,015,901	1,210,893
2031	215,900	210,717	199,262	221,678	716,600	717,566	662,977	770,605	201,000	189,022	152,449	226,096	1,133,500	1,117,305	1,014,688	1,218,379
2032	222,100	215,608	204,080	226,848	717,900	718,605	661,319	773,971	198,300	186,247	147,845	225,053	1,138,300	1,120,460	1,013,245	1,225,872
2033	228,000	220,262	208,280	231,597	719,200	719,445	659,724	777,379	195,200	183,606	143,906	224,296	1,142,400	1,123,313	1,011,909	1,233,271
2034	233,500	225,225	212,827	237,255	720,100	719,557	657,575	780,192	191,900	181,155	140,222	223,165	1,145,500	1,125,937	1,010,624	1,240,612
2035	238,900	230,101	217,222	243,194	720,900	719,192	655,052	781,317	188,600	178,470	135,955	223,141	1,148,400	1,127,763	1,008,229	1,247,652
2036	244,400	234,565	221,552	247,705	721,100	718,963	652,366	783,662	185,100	176,290	132,396	223,266	1,150,600	1,129,818	1,006,314	1,254,634
2037	249,800	239,346	225,880	253,136	721,200	718,056	649,245	785,752	181,600	173,906	128,188	222,302	1,152,600	1,131,308	1,003,313	1,261,189
2038	255,300	244,389	230,256	258,297	720,500	716,758	644,027	787,100	177,900	172,128	124,484	222,077	1,153,700	1,133,276	998,768	1,267,473
2039	261,300	249,879	234,942	264,146	719,100	714,558	639,075	788,193	174,200	170,448	119,805	221,735	1,154,600	1,134,884	993,823	1,274,074
2040	267,700	255,983	240,587	270,409	716,800	711,008	632,598	787,540	170,600	168,938	116,424	223,465	1,155,100	1,135,929	989,609	1,281,414

3.B.8 Malaysian Indian male population forecasts

	Old age (60 and above)				Working age (15-59)				Children (0-14)				Total (0-80)			
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi
2010	70,000	73,344	71,624	74,982	643,900	652,851	647,799	657,754	252,200	249,981	247,042	253,088	966,100	976,175	966,465	985,824
2011	72,600	76,878	73,949	79,715	652,300	660,555	652,351	668,683	248,900	247,527	242,726	252,745	973,800	984,960	969,026	1,001,143
2012	76,300	80,660	77,089	84,239	659,300	668,130	657,223	678,804	245,700	245,080	238,534	252,116	981,300	993,870	972,846	1,015,158
2013	80,200	84,777	80,714	89,064	665,800	675,033	661,766	687,923	242,700	242,692	234,465	251,319	988,700	1,002,501	976,946	1,028,306
2014	84,400	89,235	84,845	94,043	672,100	681,161	665,514	696,057	240,000	240,077	230,107	250,775	996,500	1,010,472	980,465	1,040,876
2015	88,800	93,993	88,808	99,199	677,900	686,810	669,059	704,241	237,400	237,428	225,812	249,364	1,004,100	1,018,231	983,679	1,052,805
2016	93,800	99,160	93,667	104,438	683,600	691,540	671,654	710,670	234,300	234,446	221,212	247,230	1,011,700	1,025,146	986,533	1,062,338
2017	98,800	104,343	98,795	109,847	688,900	695,817	674,373	716,608	231,500	231,552	217,224	245,883	1,019,200	1,031,712	990,392	1,072,338
2018	104,100	109,605	103,332	115,810	693,000	699,303	675,891	722,063	229,200	228,783	213,148	244,036	1,026,300	1,037,691	992,371	1,081,909
2019	109,600	114,917	108,451	121,370	696,800	702,447	677,254	727,347	227,100	226,137	209,401	243,142	1,033,500	1,043,501	995,105	1,091,859
2020	115,000	120,424	113,600	127,233	699,800	705,034	677,636	732,018	225,400	223,657	206,133	242,028	1,040,200	1,049,115	997,369	1,101,279
2021	120,800	126,123	118,865	133,152	702,300	707,013	678,054	735,857	224,200	221,559	202,780	240,580	1,047,300	1,054,695	999,699	1,109,589
2022	126,500	131,727	124,017	139,279	703,800	707,917	677,441	739,272	223,200	219,579	198,919	240,949	1,053,500	1,059,223	1,000,376	1,119,499
2023	132,400	137,037	128,777	145,462	704,900	708,327	676,236	741,185	222,400	217,773	196,280	240,494	1,059,700	1,063,137	1,001,293	1,127,141
2024	137,800	141,942	132,996	150,839	706,200	708,492	674,632	742,984	221,300	216,744	193,900	240,643	1,065,300	1,067,178	1,001,527	1,134,465
2025	142,900	146,296	136,935	156,170	707,600	711,057	675,197	747,536	220,500	213,835	189,695	238,883	1,071,000	1,071,188	1,001,827	1,142,589
2026	147,500	150,259	140,258	160,508	709,100	713,453	675,325	752,083	219,300	210,674	185,478	236,827	1,075,900	1,074,386	1,001,061	1,149,418
2027	151,900	154,033	143,212	164,632	711,100	715,924	675,772	757,070	217,800	207,391	181,425	234,881	1,080,800	1,077,347	1,000,409	1,156,583
2028	156,000	157,608	145,983	168,128	713,100	717,921	675,115	761,476	215,900	204,027	177,068	232,855	1,085,000	1,079,556	998,166	1,162,459
2029	159,900	161,128	149,404	171,873	715,200	719,547	674,742	765,558	213,800	200,775	172,940	230,523	1,088,900	1,081,450	997,085	1,167,954
2030	163,800	164,693	152,531	175,921	717,100	720,928	673,867	770,419	211,300	197,584	168,723	228,954	1,092,200	1,083,204	995,121	1,175,294
2031	167,600	168,209	155,878	179,979	718,700	721,411	671,372	774,292	208,700	194,466	164,418	227,112	1,095,000	1,084,086	991,669	1,181,383
2032	171,500	171,573	158,735	183,840	720,100	722,131	670,462	777,720	205,700	191,703	160,680	225,147	1,097,300	1,085,407	989,878	1,186,707
2033	175,400	175,045	161,732	187,871	720,800	722,000	667,494	780,097	202,400	188,990	156,215	223,276	1,098,600	1,086,036	985,441	1,191,244
2034	179,100	178,745	165,057	192,349	721,300	721,635	664,531	781,879	199,100	186,446	151,887	223,012	1,099,500	1,086,826	981,474	1,197,240
2035	183,100	182,442	168,338	196,711	721,700	720,326	661,497	782,166	195,700	183,853	146,803	222,556	1,100,500	1,086,621	976,638	1,201,433
2036	187,100	186,345	172,086	201,343	722,000	718,891	656,786	783,652	192,200	181,353	142,550	221,299	1,101,300	1,086,590	971,421	1,206,294
2037	191,300	190,335	174,991	206,566	721,700	716,685	651,385	783,580	188,500	178,882	138,671	221,988	1,101,500	1,085,902	965,047	1,212,134
2038	195,800	194,779	178,860	211,315	721,500	713,634	644,883	783,984	184,900	176,734	134,014	222,428	1,102,200	1,085,147	957,757	1,217,728
2039	200,900	199,440	183,550	216,342	720,400	709,899	638,957	781,738	181,400	174,953	129,897	223,511	1,102,700	1,084,292	952,403	1,221,591
2040	206,100	204,685	187,785	222,106	718,800	705,639	631,158	780,034	177,800	173,368	125,517	225,879	1,102,700	1,083,692	944,460	1,228,019

3.B.9 Malaysian Indian female (a) and male (b) population ageing indicators

	Old-age dependency ratio				% Old (60+)				Life expectancy at birth		
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	coherent.mean	coherent.lo	coherent.hi
2010	13%	13%	13%	13%	8%	9%	9%	9%	75.56	75.33	75.75
2011	13%	14%	13%	14%	9%	9%	9%	9%	75.87	75.60	76.12
2012	14%	14%	14%	14%	9%	9%	9%	10%	76.04	75.76	76.37
2013	14%	15%	14%	15%	10%	10%	10%	10%	76.29	75.93	76.56
2014	15%	15%	15%	16%	10%	10%	10%	10%	76.48	76.15	76.81
2015	16%	16%	16%	16%	10%	11%	11%	11%	76.73	76.36	77.07
2016	16%	17%	17%	17%	11%	11%	11%	11%	76.92	76.56	77.27
2017	17%	18%	17%	18%	11%	12%	12%	12%	77.17	76.77	77.53
2018	18%	19%	18%	19%	12%	12%	12%	12%	77.37	76.98	77.76
2019	19%	19%	19%	20%	13%	13%	13%	13%	77.61	77.19	77.99
2020	20%	20%	20%	21%	13%	13%	13%	13%	77.81	77.41	78.17
2021	21%	21%	21%	21%	14%	14%	14%	14%	78.05	77.60	78.45
2022	22%	22%	22%	22%	14%	15%	15%	14%	78.24	77.81	78.65
2023	23%	23%	23%	23%	15%	15%	15%	15%	78.47	78.01	78.84
2024	24%	24%	24%	24%	15%	16%	16%	15%	78.66	78.20	79.10
2025	25%	25%	25%	25%	16%	16%	16%	16%	78.88	78.43	79.32
2026	26%	26%	26%	25%	17%	17%	17%	16%	79.08	78.57	79.56
2027	27%	26%	27%	26%	17%	17%	17%	17%	79.30	78.78	79.76
2028	28%	27%	27%	27%	18%	18%	18%	17%	79.49	79.01	79.96
2029	28%	28%	28%	28%	18%	18%	19%	18%	79.71	79.20	80.17
2030	29%	29%	29%	28%	19%	18%	19%	18%	79.90	79.39	80.43
2031	30%	29%	30%	29%	19%	19%	20%	18%	80.11	79.54	80.60
2032	31%	30%	31%	29%	20%	19%	20%	19%	80.30	79.74	80.79
2033	32%	31%	32%	30%	20%	20%	21%	19%	80.50	79.93	81.00
2034	32%	31%	32%	30%	20%	20%	21%	19%	80.69	80.12	81.21
2035	33%	32%	33%	31%	21%	20%	22%	19%	80.90	80.35	81.42
2036	34%	33%	34%	32%	21%	21%	22%	20%	81.08	80.51	81.64
2037	35%	33%	35%	32%	22%	21%	23%	20%	81.28	80.70	81.84
2038	35%	34%	36%	33%	22%	22%	23%	20%	81.47	80.87	82.06
2039	36%	35%	37%	34%	23%	22%	24%	21%	81.67	81.04	82.26
2040	37%	36%	38%	34%	23%	23%	24%	21%	81.85	81.24	82.46

(e)

	Old-age dependency ratio				% Old (60+)				Life expectancy at birth		
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	coherent.mean	coherent.lo	coherent.hi
2010	11%	11%	11%	11%	7%	8%	7%	8%	68.06	67.74	68.32
2011	11%	12%	11%	12%	7%	8%	8%	8%	68.31	67.87	68.69
2012	12%	12%	12%	12%	8%	8%	8%	8%	68.54	67.98	69.05
2013	12%	13%	12%	13%	8%	8%	8%	9%	68.79	68.11	69.38
2014	13%	13%	13%	14%	8%	9%	9%	9%	69.05	68.26	69.67
2015	13%	14%	13%	14%	9%	9%	9%	9%	69.31	68.40	70.05
2016	14%	14%	14%	15%	9%	10%	9%	10%	69.56	68.56	70.34
2017	14%	15%	15%	15%	10%	10%	10%	10%	69.80	68.71	70.63
2018	15%	16%	15%	16%	10%	11%	10%	11%	70.03	68.87	70.92
2019	16%	16%	16%	17%	11%	11%	11%	11%	70.25	69.11	71.23
2020	16%	17%	17%	17%	11%	11%	11%	12%	70.47	69.24	71.50
2021	17%	18%	18%	18%	12%	12%	12%	12%	70.70	69.41	71.77
2022	18%	19%	18%	19%	12%	12%	12%	12%	70.93	69.56	72.10
2023	19%	19%	19%	20%	12%	13%	13%	13%	71.16	69.71	72.35
2024	20%	20%	20%	20%	13%	13%	13%	13%	71.38	69.91	72.56
2025	20%	21%	20%	21%	13%	14%	14%	14%	71.60	70.24	72.91
2026	21%	21%	21%	21%	14%	14%	14%	14%	71.82	70.41	73.12
2027	21%	22%	21%	22%	14%	14%	14%	14%	72.03	70.65	73.36
2028	22%	22%	22%	22%	14%	15%	15%	14%	72.25	70.80	73.63
2029	22%	22%	22%	22%	15%	15%	15%	15%	72.47	71.03	73.91
2030	23%	23%	23%	23%	15%	15%	15%	15%	72.68	71.13	74.11
2031	23%	23%	23%	23%	15%	16%	16%	15%	72.90	71.39	74.32
2032	24%	24%	24%	24%	16%	16%	16%	15%	73.11	71.51	74.59
2033	24%	24%	24%	24%	16%	16%	16%	16%	73.32	71.75	74.81
2034	25%	25%	25%	25%	16%	16%	17%	16%	73.53	71.87	74.99
2035	25%	25%	25%	25%	17%	17%	17%	16%	73.74	72.11	75.27
2036	26%	26%	26%	26%	17%	17%	18%	17%	73.95	72.35	75.55
2037	27%	27%	27%	26%	17%	18%	18%	17%	74.16	72.53	75.77
2038	27%	27%	28%	27%	18%	18%	19%	17%	74.36	72.73	75.93
2039	28%	28%	29%	28%	18%	18%	19%	18%	74.57	72.91	76.18
2040	29%	29%	30%	28%	19%	19%	20%	18%	74.77	73.19	76.37

(f)

3.B.10 Malaysian Chinese female population forecasts

	Old age (60 and above)				Working age (15-59)				Children (0-14)				Total (0-80)			
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi
2010	381,100	396,129	388,924	403,210	2,030,200	2,052,592	2,037,874	2,067,804	705,100	695,164	683,606	707,673	3,116,400	3,143,885	3,110,403	3,178,686
2011	397,900	409,771	398,789	420,987	2,051,600	2,075,411	2,049,696	2,099,736	692,600	686,656	666,332	709,697	3,142,100	3,171,838	3,114,817	3,230,420
2012	415,900	424,157	409,867	438,060	2,070,200	2,098,282	2,065,243	2,131,767	680,900	678,307	650,109	710,422	3,167,000	3,200,745	3,125,219	3,280,249
2013	433,900	438,680	420,952	455,307	2,087,100	2,120,731	2,079,571	2,161,823	669,900	670,480	635,329	708,031	3,190,900	3,229,891	3,135,852	3,325,160
2014	453,000	453,251	432,611	472,437	2,102,800	2,140,723	2,091,309	2,188,859	659,500	661,339	621,611	704,662	3,215,300	3,255,313	3,145,531	3,365,958
2015	472,900	469,872	446,394	491,215	2,116,800	2,160,364	2,104,821	2,217,467	649,600	652,708	605,520	705,238	3,239,300	3,282,945	3,156,734	3,413,920
2016	493,600	487,713	461,386	512,583	2,131,400	2,178,701	2,114,534	2,244,228	637,800	642,934	589,517	704,296	3,262,800	3,309,348	3,165,438	3,461,107
2017	515,000	505,369	475,245	532,988	2,142,100	2,194,757	2,120,773	2,269,839	628,700	632,784	573,919	700,571	3,285,800	3,332,910	3,169,936	3,503,398
2018	536,900	523,548	491,010	553,488	2,150,700	2,209,849	2,126,077	2,295,236	620,400	623,183	557,274	698,024	3,308,000	3,356,579	3,174,361	3,546,748
2019	558,900	541,298	505,761	574,202	2,157,900	2,223,719	2,128,874	2,317,722	612,800	614,271	542,622	695,655	3,329,600	3,379,287	3,177,257	3,587,579
2020	580,600	558,781	521,015	593,779	2,163,300	2,236,597	2,131,495	2,342,337	606,300	605,850	527,297	694,821	3,350,200	3,401,228	3,179,807	3,630,936
2021	602,200	576,111	534,835	613,148	2,166,500	2,249,007	2,132,743	2,367,930	601,200	599,229	511,742	695,122	3,369,900	3,424,347	3,179,320	3,676,200
2022	623,400	592,950	549,992	632,286	2,167,600	2,258,940	2,132,205	2,390,679	597,000	593,769	499,592	696,649	3,388,000	3,445,659	3,181,789	3,719,614
2023	644,600	609,149	564,442	651,853	2,168,100	2,266,111	2,128,301	2,408,720	592,700	589,532	488,923	699,809	3,405,400	3,464,792	3,181,666	3,760,382
2024	666,100	626,038	578,690	671,070	2,166,700	2,271,428	2,124,026	2,426,446	588,600	586,800	480,346	703,827	3,421,400	3,484,267	3,183,061	3,801,344
2025	687,800	643,399	593,672	691,203	2,162,900	2,280,098	2,121,137	2,449,716	585,600	579,772	466,738	703,200	3,436,300	3,503,269	3,181,547	3,844,119
2026	710,100	661,321	611,139	710,599	2,158,100	2,287,306	2,116,592	2,471,167	582,000	572,656	454,174	696,863	3,450,200	3,521,283	3,181,905	3,878,628
2027	732,900	679,059	626,719	728,955	2,152,400	2,293,873	2,107,056	2,490,058	577,700	565,476	444,079	693,339	3,463,000	3,538,408	3,177,854	3,912,352
2028	756,100	695,710	639,789	749,296	2,146,200	2,300,123	2,097,367	2,512,302	572,800	557,173	430,534	689,057	3,475,100	3,553,005	3,167,690	3,950,655
2029	778,600	710,687	651,561	768,001	2,140,100	2,308,080	2,093,295	2,531,525	567,200	549,580	420,534	683,179	3,485,900	3,568,347	3,165,390	3,982,705
2030	800,100	723,754	659,278	784,060	2,134,600	2,315,487	2,086,147	2,553,789	560,900	543,058	405,868	678,088	3,495,600	3,582,298	3,151,293	4,015,937
2031	820,300	735,966	667,089	797,917	2,129,400	2,323,334	2,077,605	2,577,047	553,800	537,740	397,434	678,342	3,503,500	3,597,040	3,142,128	4,053,306
2032	839,400	748,109	675,269	814,063	2,124,500	2,331,115	2,072,548	2,600,237	546,400	532,297	388,840	676,908	3,510,300	3,611,521	3,136,657	4,091,209
2033	857,400	759,934	686,897	825,643	2,119,300	2,337,864	2,066,051	2,616,262	538,400	527,764	381,950	676,831	3,515,100	3,625,562	3,134,898	4,118,736
2034	874,400	772,866	696,534	841,090	2,114,300	2,342,891	2,058,961	2,635,733	530,000	524,404	373,228	677,537	3,518,700	3,640,161	3,128,723	4,154,360
2035	890,800	784,650	707,405	854,801	2,108,500	2,347,534	2,051,300	2,654,206	521,400	520,181	362,434	676,594	3,520,700	3,652,365	3,121,139	4,185,601
2036	907,200	795,528	717,318	866,399	2,103,300	2,351,780	2,037,549	2,675,244	512,400	516,948	352,932	683,686	3,522,900	3,664,256	3,107,799	4,225,328
2037	923,400	807,042	727,184	880,991	2,098,200	2,356,719	2,025,794	2,695,948	503,200	513,533	342,546	689,919	3,524,800	3,677,293	3,095,524	4,266,857
2038	939,900	819,241	736,917	897,017	2,092,600	2,360,580	2,012,491	2,713,965	493,800	511,367	331,747	696,253	3,526,300	3,691,189	3,081,155	4,307,235
2039	957,500	831,322	746,973	912,352	2,085,700	2,361,683	1,999,817	2,725,873	484,600	509,783	320,419	709,052	3,527,800	3,702,789	3,067,209	4,347,277
2040	976,500	845,378	759,523	928,493	2,077,600	2,360,852	1,986,280	2,743,585	475,200	508,683	313,549	719,714	3,529,300	3,714,914	3,059,351	4,391,792

3.B.11 Malaysian Chinese male population forecasts

	Old age (60 and above)				Working age (15-59)				Children (0-14)				Total (0-80)			
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi
2010	396,900	413,401	406,815	420,749	2,170,700	2,192,549	2,176,807	2,208,592	746,500	735,392	724,491	747,308	3,314,100	3,341,343	3,308,113	3,376,648
2011	410,500	430,050	419,411	440,643	2,189,400	2,213,032	2,186,952	2,238,177	732,900	725,598	706,044	744,623	3,332,800	3,368,680	3,312,407	3,423,443
2012	426,900	445,647	430,067	460,922	2,203,500	2,231,856	2,198,544	2,265,083	720,500	716,616	688,584	742,913	3,350,900	3,394,119	3,317,194	3,468,918
2013	443,200	461,837	443,030	479,351	2,216,200	2,250,598	2,211,157	2,290,298	708,900	708,579	673,653	742,797	3,368,300	3,421,014	3,327,840	3,512,446
2014	460,500	478,536	457,789	498,562	2,227,400	2,268,515	2,220,685	2,315,394	697,900	700,741	659,418	742,154	3,385,800	3,447,792	3,337,892	3,556,110
2015	478,200	496,157	472,576	518,945	2,237,000	2,284,983	2,228,713	2,340,462	687,400	692,500	644,781	741,207	3,402,600	3,473,640	3,346,071	3,600,614
2016	496,800	515,272	489,337	540,992	2,247,700	2,300,658	2,235,841	2,363,316	675,000	683,218	627,978	738,592	3,419,500	3,499,148	3,353,156	3,642,900
2017	515,600	534,847	506,410	562,452	2,254,900	2,313,859	2,240,887	2,384,764	664,700	672,418	610,609	735,252	3,435,200	3,521,124	3,357,907	3,682,468
2018	534,800	553,882	522,562	584,092	2,260,000	2,325,491	2,243,241	2,404,260	655,100	662,699	595,631	731,272	3,449,900	3,542,073	3,361,434	3,719,623
2019	554,100	573,237	540,996	604,696	2,263,100	2,336,376	2,246,190	2,424,402	646,800	654,113	580,625	731,208	3,464,000	3,563,726	3,367,811	3,760,305
2020	573,200	592,096	557,738	625,961	2,264,400	2,345,340	2,248,301	2,440,133	639,400	646,050	565,336	731,427	3,477,000	3,583,485	3,371,375	3,797,521
2021	592,700	610,785	574,812	645,798	2,262,500	2,352,427	2,243,823	2,456,616	634,000	638,885	549,618	730,576	3,489,200	3,602,097	3,368,253	3,832,990
2022	612,100	629,148	589,302	668,061	2,259,900	2,357,033	2,238,133	2,469,651	628,300	633,507	535,922	732,537	3,500,300	3,619,688	3,363,357	3,870,248
2023	631,000	646,640	604,566	687,770	2,256,400	2,360,486	2,232,913	2,482,000	622,600	629,571	526,561	734,919	3,510,000	3,636,697	3,364,040	3,904,688
2024	649,200	664,171	619,889	707,402	2,251,500	2,362,356	2,224,787	2,496,481	618,000	627,726	517,294	740,051	3,518,700	3,654,253	3,361,971	3,943,933
2025	666,200	680,163	635,082	724,433	2,244,800	2,368,458	2,218,764	2,515,873	614,700	621,705	507,622	738,588	3,525,700	3,670,325	3,361,469	3,978,895
2026	682,000	696,006	648,385	742,122	2,238,900	2,376,062	2,211,339	2,538,948	611,000	614,138	495,321	736,260	3,531,900	3,686,205	3,355,044	4,017,330
2027	697,300	711,714	662,415	759,958	2,233,300	2,384,292	2,205,648	2,561,770	606,400	605,204	484,412	731,249	3,537,000	3,701,210	3,352,475	4,052,977
2028	711,800	725,979	675,124	775,346	2,228,100	2,392,728	2,197,070	2,583,204	601,100	596,571	474,792	730,331	3,541,000	3,715,277	3,346,987	4,088,881
2029	726,000	738,869	685,367	790,852	2,222,500	2,400,196	2,190,980	2,608,183	595,100	587,670	462,932	727,910	3,543,600	3,726,735	3,339,279	4,126,946
2030	740,100	751,842	696,227	805,832	2,217,800	2,406,430	2,181,624	2,630,940	588,800	580,195	449,574	729,151	3,546,700	3,738,467	3,327,425	4,165,924
2031	754,100	764,369	705,300	821,694	2,213,500	2,412,382	2,171,056	2,654,334	582,000	572,705	436,801	726,190	3,549,600	3,749,455	3,313,157	4,202,218
2032	768,100	776,664	716,206	836,058	2,210,000	2,417,742	2,158,050	2,677,158	575,000	566,749	427,850	721,907	3,553,100	3,761,154	3,302,106	4,235,122
2033	781,900	789,781	727,325	850,427	2,206,900	2,421,888	2,145,427	2,695,340	567,900	560,923	416,389	722,262	3,556,700	3,772,592	3,289,142	4,268,029
2034	795,600	803,007	738,718	867,063	2,204,000	2,424,153	2,135,953	2,713,919	560,400	554,901	406,910	720,326	3,560,000	3,782,061	3,281,580	4,301,308
2035	808,800	816,918	749,854	884,145	2,201,000	2,425,907	2,122,823	2,726,031	552,500	549,240	395,022	722,461	3,562,300	3,792,064	3,267,698	4,332,636
2036	822,100	831,259	764,550	902,001	2,197,900	2,427,858	2,110,292	2,743,473	544,200	544,196	386,272	729,402	3,564,200	3,803,313	3,261,114	4,374,876
2037	835,400	845,220	778,211	916,551	2,195,100	2,428,479	2,095,592	2,761,992	535,800	538,554	374,444	732,130	3,566,300	3,812,254	3,248,247	4,410,673
2038	848,900	859,430	790,459	932,809	2,191,500	2,427,790	2,076,739	2,782,460	527,100	534,453	360,919	741,816	3,567,500	3,821,673	3,228,117	4,457,084
2039	863,300	873,852	803,950	947,959	2,187,300	2,426,277	2,059,386	2,799,215	518,300	531,665	349,872	755,624	3,568,900	3,831,794	3,213,208	4,502,798
2040	878,100	888,179	817,192	963,583	2,182,100	2,423,422	2,042,906	2,818,038	509,600	529,881	337,114	768,454	3,569,800	3,841,482	3,197,212	4,550,074

3.B.12 Malaysian Chinese female (a) and male (b) population ageing indicators

	Old-age dependency ratio				% Old (60+)				Life expectancy at birth		
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	coherent.mean	coherent.lo	coherent.hi
2010	19%	19%	19%	19%	12%	13%	13%	13%	79.02	78.83	79.22
2011	19%	20%	19%	20%	13%	13%	13%	13%	79.27	79.01	79.49
2012	20%	20%	20%	21%	13%	13%	13%	13%	79.52	79.23	79.85
2013	21%	21%	20%	21%	14%	14%	13%	14%	79.77	79.41	80.09
2014	22%	21%	21%	22%	14%	14%	14%	14%	79.93	79.61	80.29
2015	22%	22%	21%	22%	15%	14%	14%	14%	80.17	79.78	80.54
2016	23%	22%	22%	23%	15%	15%	15%	15%	80.32	79.96	80.72
2017	24%	23%	22%	23%	16%	15%	15%	15%	80.55	80.14	80.94
2018	25%	24%	23%	24%	16%	16%	15%	16%	80.70	80.31	81.15
2019	26%	24%	24%	25%	17%	16%	16%	16%	80.93	80.46	81.33
2020	27%	25%	24%	25%	17%	16%	16%	16%	81.08	80.64	81.60
2021	28%	26%	25%	26%	18%	17%	17%	17%	81.29	80.80	81.82
2022	29%	26%	26%	26%	18%	17%	17%	17%	81.44	80.99	82.03
2023	30%	27%	27%	27%	19%	18%	18%	17%	81.65	81.14	82.18
2024	31%	28%	27%	28%	19%	18%	18%	18%	81.80	81.29	82.35
2025	32%	28%	28%	28%	20%	18%	19%	18%	82.00	81.45	82.59
2026	33%	29%	29%	29%	21%	19%	19%	18%	82.15	81.59	82.74
2027	34%	30%	30%	29%	21%	19%	20%	19%	82.35	81.78	82.98
2028	35%	30%	31%	30%	22%	20%	20%	19%	82.50	81.94	83.14
2029	36%	31%	31%	30%	22%	20%	21%	19%	82.69	82.09	83.31
2030	37%	31%	32%	31%	23%	20%	21%	20%	82.84	82.25	83.47
2031	39%	32%	32%	31%	23%	20%	21%	20%	83.03	82.41	83.66
2032	40%	32%	33%	31%	24%	21%	22%	20%	83.18	82.55	83.83
2033	40%	33%	33%	32%	24%	21%	22%	20%	83.36	82.74	84.01
2034	41%	33%	34%	32%	25%	21%	22%	20%	83.51	82.84	84.23
2035	42%	33%	34%	32%	25%	21%	23%	20%	83.69	83.02	84.34
2036	43%	34%	35%	32%	26%	22%	23%	21%	83.83	83.12	84.53
2037	44%	34%	36%	33%	26%	22%	23%	21%	84.01	83.32	84.70
2038	45%	35%	37%	33%	27%	22%	24%	21%	84.16	83.47	84.92
2039	46%	35%	37%	33%	27%	22%	24%	21%	84.33	83.63	85.04
2040	47%	36%	38%	34%	28%	23%	25%	21%	84.48	83.79	85.24

(g)

	Old-age dependency ratio				% Old (60+)				Life expectancy at birth		
Year	DoSM	coherent.mean	coherent.lo	coherent.hi	DoSM	coherent.mean	coherent.lo	coherent.hi	coherent.mean	coherent.lo	coherent.hi
2010	18%	19%	19%	19%	12%	12%	12%	12%	74.00	73.80	74.18
2011	19%	19%	19%	20%	12%	13%	13%	13%	74.23	73.97	74.53
2012	19%	20%	20%	20%	13%	13%	13%	13%	74.57	74.24	74.93
2013	20%	21%	20%	21%	13%	14%	13%	14%	74.81	74.42	75.20
2014	21%	21%	21%	22%	14%	14%	14%	14%	75.14	74.72	75.57
2015	21%	22%	21%	22%	14%	14%	14%	14%	75.38	74.93	75.85
2016	22%	22%	22%	23%	15%	15%	15%	15%	75.70	75.22	76.22
2017	23%	23%	23%	24%	15%	15%	15%	15%	75.93	75.42	76.46
2018	24%	24%	23%	24%	16%	16%	16%	16%	76.22	75.71	76.80
2019	24%	25%	24%	25%	16%	16%	16%	16%	76.44	75.91	77.02
2020	25%	25%	25%	26%	16%	17%	17%	16%	76.71	76.18	77.30
2021	26%	26%	26%	26%	17%	17%	17%	17%	76.91	76.38	77.52
2022	27%	27%	26%	27%	17%	17%	18%	17%	77.17	76.58	77.83
2023	28%	27%	27%	28%	18%	18%	18%	18%	77.36	76.74	78.00
2024	29%	28%	28%	28%	18%	18%	18%	18%	77.61	76.96	78.30
2025	30%	29%	29%	29%	19%	19%	19%	18%	77.81	77.10	78.48
2026	30%	29%	29%	29%	19%	19%	19%	18%	78.06	77.35	78.75
2027	31%	30%	30%	30%	20%	19%	20%	19%	78.26	77.54	78.95
2028	32%	30%	31%	30%	20%	20%	20%	19%	78.51	77.78	79.18
2029	33%	31%	31%	30%	20%	20%	21%	19%	78.71	77.93	79.49
2030	33%	31%	32%	31%	21%	20%	21%	19%	78.96	78.18	79.71
2031	34%	32%	32%	31%	21%	20%	21%	20%	79.16	78.39	79.93
2032	35%	32%	33%	31%	22%	21%	22%	20%	79.41	78.66	80.20
2033	35%	33%	34%	32%	22%	21%	22%	20%	79.61	78.85	80.42
2034	36%	33%	35%	32%	22%	21%	23%	20%	79.85	79.12	80.68
2035	37%	34%	35%	32%	23%	22%	23%	20%	80.05	79.28	80.94
2036	37%	34%	36%	33%	23%	22%	23%	21%	80.28	79.48	81.13
2037	38%	35%	37%	33%	23%	22%	24%	21%	80.47	79.71	81.35
2038	39%	35%	38%	34%	24%	22%	24%	21%	80.70	79.90	81.57
2039	39%	36%	39%	34%	24%	23%	25%	21%	80.89	80.05	81.84
2040	40%	37%	40%	34%	25%	23%	26%	21%	81.12	80.24	82.05

(h)

Chapter 4

Paper 3

Malaysian Long Term Care For Elderly: Future Demand, Costs and Effectiveness

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Abstract

This paper projects the number of elderly Malaysians who are disabled and require long term care up to the year 2040. The transition probabilities of lives becoming disabled and the extent to which they are disabled is estimated using the approach of Rickayzen & Walsh (2002). We extend this model to include an alternative method for mortality improvement—the so-called developed-developing countries coherence model—in projecting the Malaysia elderly by disability levels. Results indicate that in comparison to 2010, the projected number of disabled elderly Malaysian by gender and disability levels will be more than triple by 2030. The associated costs of public long term care relative to 2012 are projected to double in real terms by 2030. In addition, the cost effectiveness of public residential care and nursing home care is evaluated and compared with an older nation, Japan. Results suggest that the public nursing home care program in Malaysia may not be cost effective.

Keywords: Malaysian Long Term Care; Multiple State Model; Healthy Life Expectancy; Costs Utility Analysis; QALY; Random Utility Model; Choice Modelling

4.1 Introduction

Population ageing affects long term care systems, particularly in terms of demand and its associated costs. Malaysian mortality and fertility is projected to decrease over the next few decades, exacerbating population ageing. Goh & Lai (2013) argues Malaysia will become an aged society by 2030—that is, when older adults aged 60 years and above reach 15% of the total population. This benchmark, has, however, already been met by the Chinese population; it is forecast to be aged in 2016 (Hassan 2012, Shair et al. 2016). These population changes, and the fact that the ageing process varies by ethnicity, pose great challenges to the government in implementing prompt and adequate provision of long term care.

An increasing proportion of older people may translate to more demand for long term care due to the higher prevalence of disability amongst the elderly (Goh & Lai 2013, Pollard 1996). Although more than two-thirds of the elderly Malaysian receive care from their family members, this form of care may no longer be sufficient in the near future (Vanzo & Chan 1994). The availability of traditional family care for the disabled elderly is shrinking due to a constant decline in births and urbanisation (Ong 2007, Dahlan et al. 2010). This issue has been extensively debated by researchers, with many of them demanding changes in Malaysia's current long term care programs (Ambigga 2011, Mafauzy 2000, Dahlan et al. 2010, Li & Khan 2012). However, the Malaysian government has yet to design a national policy exclusively on long term care (Ong 2002).

The provision of long term care is costly. Hence, accurate estimates of the number of people who are likely to need long-term care are important (Rickayzen & Walsh 2002). To the best of our knowledge, no such number exists for Malaysia. This paper seeks to fill the gap and aims to provide some answers to the following two broad research questions. Firstly, what is the likely number of elderly requiring long term care in the future and what are their associated costs? Secondly, how effective are the current public long term care programs provided by the Malaysian government?

In order to estimate the likely number of people in Malaysia requiring long term care over the coming decades, we follow Rickayzen & Walsh (2002) to determine the transition probabilities of disablement and its extent. Leung (2004) used similar methods for Australia. We extend both Rickayzen & Walsh (2002) and Leung (2004) by using an alternative method for mortality improvement—a developed-developing countries coherence model. In addition, we include an economic evaluation of long term care programs provided by the Malaysian government and compare its effectiveness with an Asian developed country, Japan.

This paper is organised as follows. Section 4.2 provides a review of the literature on Malaysia's currrent long term care programs, the methods to estimate the likely number of people requiring long term care, the economic evaluation of long term care programs. Section 4.3 describes the data used for this research. Methods used in the multiple state modelling and cost utility analysis are described in section 4.4. Section 4.5 provides results and analysis. Section 4.6 concludes.

4.2 Literature Review

4.2.1 Malaysian long term care

Malaysia's public long term care is a safety net program that provides welfare for very poor older people (income below a specified threshold). The public programs include both formal and informal care, which are summarised in Table 4.1.

In 2012 the formal care programs included 11 care institutions for the elderly which comprised nine residential homes and two nursing homes. Residents of these institutional homes are elderly age 60 and above, the majority of whom do not have family members or caregivers to provide care. While residential homes accept only those who are independent enough to take care of themselves, nursing homes provide care intensively around the clock to more severely disabled older adults.

For informal care, monthly cash payments are given to caregivers or family members of poor elderly with income below a threshold. In addition, day care centres may exist within the community to provide temporary care services for elderly parents while their children are at work. Up until 2016, there has been no formal funding for Malaysian long term care. Nevertheless the costs of receiving care from these public institutions are fully subsidised by the government[1].

[1] All information regarding the Malaysian public long term care system were obtained from

Table 4.1: Existing Malaysian public long term care programs which include formal care (residential care and nursing home care) and informal care (home care and community care).

Type of care	Description
Residential formal care ("Rumah Sri Kenanga")	Provides a home for elderly who are aged 60 years and above, below the income threshold and have no family to provide care. Must be independent or require low level of care to perform the activities of daily life.
Nursing Home formal care ("Rumah Ehsan")	Provides a home and extensive care for elderly aged 60 years and above, below the income threshold and have no family to provide care. Patients have high levels of disability and are dependent on care around the clock.
Cash payment for home care	Provides a monthly cash allowance to caregivers among family members to poor elderly who have income below the threshold.
Day care centre in the community	A community care setting which provides temporary care during the daytime.

Data indicates that the availability of public care is very limited covering up to only 0.09%[2] of the total elderly population nationwide. This low level of coverage was meant to only provide benefits for the destitute group[3]. Current government policy on long term care puts strong emphasis on family members being responsible for older people. There is some economic motivation in the form of a tax deduction of MYR$1,000 (USD$247)[4] for medical expenses incurred by ones parents and MYR$3,000 (USD$741)[4] deduction for the purchase of any necessary basic supporting equipment for disabled parents (Vanzo & Chan 1994). This is clearly consistent with the government's stand on encouraging family support for the elderly—the government steps in mainly when family support is not feasible.

Despite the informal care incentives, the demand for formal or institutional care from the private sector has grown substantially over the years. The number of private nursing homes has increased from 50 in 2005 to 209 in 2007, an increase of 108% per year. The average monthly cost per person for private nursing home care ranges from MYR$2,000 (USD$493)[4] to MYR$5,000 (USD$1,235)[4] (Dahlan et al. 2010). Relative to the restricted coverage of public long term care, together with a decrease in births and an increase in labour force participation rates among females, the demand for these private nursing home care places is expected to continue increasing sharply into the future (Choo et al. 2003, Li & Khan 2012). In addition, findings from Vanzo & Chan (1994) suggest that the number of children significantly and positively affect the choice of living arrangement of an elderly parent—a decrease in the number of children reduces the likelihood of an elderly parent co-residing with his or her adult children, hence decreasing the

the Ministry for Women, Family and Community website at `http://kpwkm.gov.my`. The Social Welfare department under this ministry is responsible for providing all public social programs for the elderly.

[2]The report from the Operational Assistant Director of Social Welfare Department in 2012 indicate 2,084 elderly people were living in public institutions in total which 1,847 of them were living in residential care and 237 were living in nursing home care. Out of the 2,084 elderly, 1,247 were males and the remaining 837 were females (Hargaemas 2012). The age-specific population estimates from the Department of Statistics Malaysia indicate that the total population of the elderly in 2012 was 2,364,300 with 1,153,500 being males and 1,210,800 being females (Hassan 2012). Hence the total number of residents (2,084) divided by total number of elderly (2,364,300), yields 0.09%.

[3]Extremely poor with income less than MYR$499 (USD$123)[4] per month (Economic Planning Unit 2014)

[4]The conversion of Malaysian Ringgit to US Dollars is based on `http://www.xe.com/currencyconverter` as at 23rd of September 2015.

chance of getting informal care from them. Therefore, pressure is likely to emerge in the future for policy changes to increase public provision of long term care.

Private long term care insurance does not currently exist in Malaysia. While the poorest elderly depend on public long term care benefits, the middle and high income elderly can obtain care from private nursing home care services at their own cost. Otherwise, elderly parents may get informal care from their children—but its availability has reduced over the years. This informal care is also costly, given that all medical and care costs are borne by the elderly or their children. Juggling full time work and care is also a difficult task. In some cases, children have to quit their permanent job or convert it to part-time in order to provide care for elderly parents. Carers Australia (2015) found that for Australia, the cost of replacing the care provided by unpaid family carers with services supplied by formal care providers would be more than AUD$30.5 billion each year. Thus, availability of private long term care insurance in the market may reduce the cost burden of long term care. Although private long term care insurance does not exist in Malaysia and is underdeveloped in most countries, it has been successfully implemented in France (Browne 2011). Alternatively, other funding methods used internationally such as social insurance in Japan (Mitchell et al. 2007, Ihara 2011), or savings from annuities like in Singapore (Choon 2008) may provide good examples for Malaysia.

4.2.2 Disability modelling

Estimating the number of people who will require long term care faces two main challenges, namely the uncertainty about the magnitude of demographic change and the evolution of disability levels by age (Kudrna et al. 2013). In order to address the first, demographic assumptions about the future population—such as low, medium or high fertility, survival and net immigration—can be applied. Alternatively, stochastic approaches which simulate the future sample paths of each of fertility, survival and net immigration, based on the past time series data distributions, can be adopted (Hyndman & Booth 2008, Shair et al. 2016). As for the second challenge, the transition rates from healthy to disabled or from mild disability to more severely disabled can be estimated using the multiple state model (Haberman & Pitacco 1998)

The estimation of transition probabilities across disability states (for example, healthy person becoming disabled or a moderately disabled person becoming severely disabled, and so on) requires national longitudinal data, which records the disability status of an individual at two points in time using two consecutive surveys (Hariyanto et al. 2013). Since we are most interested in estimating the probabilities of transition from one year to the next, ideally the survey should be taken annually. Nevertheless, longitudinal data is often unavailable, or limited to a smaller population, in many countries—including Malaysia. One may use other countries' longitudinal survey data, such as National Long Term Care Survey in the U.S. but it may well misrepresent the disability status of the Malaysian population.

In order to address such data limitations, Rickayzen & Walsh (2002) developed a method for estimating the transition probabilities of disablement using cross sectional data which measures the disability status of individuals only at one point in time. They built a functional form for the transition probabilities in a multiple state model. Parameters in the model are estimated in such a way that the initial prevalence rates are replicated over a one year period. This model was used to project the number of people in a variety of disability categories to indicate the future long term care needs of the U.K. population.

Leung (2004) used the Rickayzen & Walsh (2002) model to project the likely number of people requiring long term care using Australia's data and proposed some modifications. Instead of using age 20 as the beginning age, his model covers all ages to allow disabilities that may have arisen at earlier ages. Leung (2004) also proposed different functions for mortality and disability improvement using a method from the Continuous Mortality Investigation Bureau (1999). In addition, the application was extended to estimate associated long term care costs.

Hariyanto et al. (2013) also adopted the same model framework to estimate the transition probabilities across levels of disability for Australia. As opposed to Leung (2004), who used 1998 data, Hariyanto et al. (2013) used more recent 2003 data. Interestingly, the model made use of two consecutive available disability prevalence rates in 1998 and 2003 to obtain the prevalence rates in every year from 1999 to 2002. Bueno (2013) showed that the same model is applicable to a developing country, Brazil. However, several formula and parameters were adjusted to accommodate Brazilian disability data.

This paper will implement a similar Rickayzen & Walsh (2002) multiple state model, but for the case of Malaysia. Transition probabilities across disability levels for those who are aged 60 and above will be estimated. Model outcomes are then used to project the number of elderly Malaysian according to four disability states—able, mild, moderate and severe. Similar to Leung (2004) and Bueno (2013), we use the reduction factor method from the Continuous Mortality Investigation Bureau (1999) report of the Institute and Faculty of Actuaries to project mortality improvement for future years. However, we extend the projection method to include another version of mortality improvement by using the developed-developing countries coherent model. This model is based on the product-ratio coherent model from Hyndman et al. (2013) which is an extension of a well known method in the mortality literature, the Lee & Carter (1992) model. This method incorporates both Malaysian male and Australian male (or Malaysian female and Australian female) mortality rates in the same model and coherently forecasts the sub-populations' mortality rates. The reason why we make use of Australia's mortality rates in estimating Malaysia's mortality improvement is because Malaysian mortality is decreasing and expected to reach the low levels which most developed countries, including Australia, have already experienced. Furthermore, this method was found, under certain circumstances, to be more accurate than a variety of other mortality forecasting models for Malaysia (Shair et al. 2016). To achieve such results, Australian male and female mortality rates were lagged by 10 years before fitting the model. That is, if the Malaysia fitting period is from 1970 to 1990, then Australian observed data from 1960 to 1980 are used.

4.2.3 Economic Evaluation of Long Term Care

Changes in demographic characteristics, social structure and economic status have shifted the direction of care of the elderly people in Malaysia away from the family (Dahlan et al. 2010). According to Dahlan et al. (2010) elderly people living in institutions experience negative effects on health and well-being as the institutional environment creates dependency and offers less privacy. Thus, the estimation of the level of life satisfaction or quality of these elderly and its cost is important in evaluating the effectiveness and efficiency of modes of long term care.

While Dahlan et al. (2010) used the Satisfaction with Life Scale (SWLS) to measure the average life satisfaction of elderly people in public long term care institutions, this paper will use a generic health-related measurement method, EQ-5D, to measure the quality adjusted life years (QALYs) of the elderly Malaysian living in institutions. In addition to QALYs, cost utility analysis is also important to identify how efficient current programs are in improving the quality of life of the elderly.

Drummond et al. (2005) pointed out that economic evaluation is a family of analytic techniques which are designed to compare two or more alternative courses of actions in terms of costs and outcomes. In the health care field, the most common form of economic evaluation method is cost-effectiveness analysis (CEA) which compares standard care with alternative care in terms of costs and effects. Effects are not expressed in monetary term as in cost-benefit analysis (CBA), but forms such as life years gained. Long term care differs from health care because of the nature of the need it meets. Rather than treating acute health problems, it encompass personal and nursing care. Quality of life of older adults improves if intervention can improve the disability or physical impairment (Eisen & Sloan 1996)

Cost utility analysis (CUA) is another type of economic evaluation that measures the benefits gained in terms of improved health or quality of life and, as such, is a narrower approach than CEA. This quality of life improvement can be estimated using a well known tool, namely QALYs (Makai 2014). QALYs are arrived at by adjusting the length of time affected by the health outcome with a health related quality of life (HRQoL) or health utility index, ranging from 0 to 1. This HRQoL index can be measured using EQ-5D: a generic measuring preference instrument based on individuals' health attributes. Section 4.5 discusses the EQ-5D measure in detail.

Bulamu et al. (2015) suggest the most commonly applied generic instrument in both community and residential care among older adults aged 65 and above was EQ-5D. Makai et al. (2014) found that the most useful instrument for economic evaluation in services aimed at older people is ASCOT, which measure the well-being and elements of the health status of the elderly. However, in order to capture the full health dimension of participants, ASCOT must be used along with EQ-5D. The EQ-5D instrument is available for many countries—Yusof et al. (2012) developed the EQ-5D value set for Malaysia. Thus, this paper will adopt the EQ-5D instrument as the tool to measure the HRQoL index of elderly Malaysian in residential care and nursing home care.

The results of CUA are typically expressed in term of costs per QALY gained by taking one program instead of another. Alternatively, the costs per QALY of one program can be compared with societal willingness to pay (WTP) for health care interventions. One program or intervention is considered effective if the cost for a QALY falls within the WTP range (Shafie et al. 2014)

4.3 Data

The multiple state model used to estimate the number of elderly Malaysian in need of long term care requires disability single year data by gender and disability levels. Malaysian disability data can be obtained from the National Health Morbidity Survey (*NHMS*) which is conducted once every 2 years. Unfortunately, at the time when we conducted this research, data according to disability severity levels were not available from this survey. These data were necessary to estimate the transition probabilities across disability levels, for example, from the able to mild, from mild to severe, etc. To overcome the limitations of the *NHMS* data, we used the WHS (2002), conducted by the Word Health Organization (WHO), to estimate the age and gender specific disability prevalence rates segregated by severity levels.

The *WHS* survey was carried out in all states of Malaysia in 2002. This survey is part of a larger project of the World Health Organization (WHO), in which many other member countries were included. The WHS (2002) sample consists of 6,037 Malaysians over the age of 18. There are nine main sets of questions, however we gather data from only question 2, which refers to the individual's health state description. There are five possible answers for every question: 1 is very good, 2 is good, 3 is moderate, 4 is bad and 5 is very bad. We recode the answer to represent disability levels such that 1 is "able", 2 is "mild", 3 is "moderate" and as data for 5 are very small, we combine these with 4 and recode as "severe".

To estimate the prevalence rates of disability for Malaysia, we collected data primarily from the following three questions,

- q2010: "Overall in the last 30 days, how much difficulty did you have with moving around?",
- q2020: "Overall in the last 30 days, how much difficulty did you have with

Table 4.2: Malaysian age-specific disability prevalence rates calculated from WHS (2002) data per 1,000 males. The able prevalence rates decrease as age increases, whereas the severe prevalence rates increase as age increases.

Age	Able	Mild	Moderate	Severe
18	904.42	81.15	11.52	2.91
25	878.04	100.75	18.24	2.98
30	868.32	101.59	22.95	7.14
35	875.40	104.21	18.78	1.61
40	882.74	97.52	13.46	6.27
45	873.57	88.92	27.88	9.63
50	834.10	130.95	29.12	5.83
55	801.19	140.03	42.38	16.73
60	772.90	153.17	53.66	20.27
65	659.21	233.69	76.51	30.58
70	594.94	258.81	114.01	32.24
75	569.10	275.37	90.16	65.36
80	476.61	290.14	122.96	110.29

self care, such as washing or dressing yourself?",

- q2050: "Overall in the last 30 days, how much difficulty did you have with concentrating or remembering things?".

The above three questions were chosen so that our disability data describes people in need of long term care services. Following Chan et al. (2004), people requiring long term care are those with mobility and self-care limitations or with cognitive impairment. Leung (2004) used the core activity restrictions (CAR), including restrictions relating to mobility, self-care and communication, to generate disability data.

Data for each question were aggregated according to age group, gender and disability level and then divided by the total exposure to estimate the prevalence rates per 1,000. The prevalence rates of the three questions were then averaged to obtain the prevalence rates for Malaysia by age and severity levels for males and females as in Tables 4.2 and 4.3, respectively.

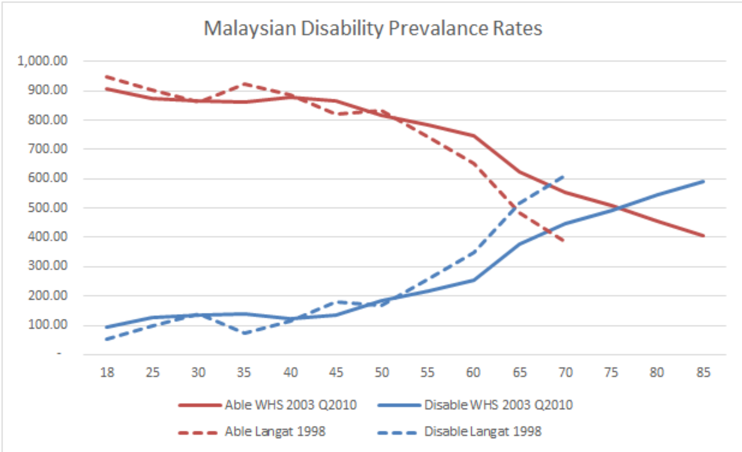
In order to establish the reliability of the calculated WHS (2002) disability prevalence rates, we compared the rates with the published prevalence rates from the disability study of Chen et al. (1983) conducted in a small district area in

Table 4.3: Malaysian age-specific disability prevalence rates calculated from WHS (2002) data per 1,000 females. Similar to males, the able prevalence rates decrease as age increases, whereas the severe prevalence rates increase as age increases.

Age	Able	Mild	Moderate	Severe
18	906.70	83.01	7.95	2.74
25	899.42	84.58	13.48	2.52
30	866.23	103.57	26.32	3.88
35	870.77	101.09	26.09	2.05
40	876.73	105.11	11.59	6.57
45	881.22	74.44	32.36	11.97
50	809.04	143.37	43.89	3.70
55	778.81	146.48	51.87	22.85
60	716.96	196.36	67.15	19.53
65	583.61	279.21	89.73	47.45
70	553.53	264.12	147.65	34.71
75	466.40	345.16	133.00	55.44
80	518.25	238.10	101.65	142.00

Malaysia called Kuala Langat in 1981. See Figure 4.1 for the comparison between WHS (2002) and the Kuala Langat prevalence rates. The two prevalence rates are broadly similar for ages 50 years and below. For ages above 50, Kuala langat disabled rates increased more rapidly than WHS (2002) and intersect the able rates at the age of 60, compared to WHS (2002) estimates that intersect at a later age, which is at age 75. We suggest two possible reasons why Kuala Langat disabled and abled prevalence rate increased and decreased at more rapid rates than that of the WHS (2002). First, the Kuala Langat survey was conducted in 1981, 22 years before the WHS (2002) survey. We know the mortality of earlier years was higher than recent years. And, as disability and mortality are usually positively correlated, one would expect disability in 1981 to be higher than that 2002. Second, the Kuala Langat respondents were restricted to a small rural area, which may lead to higher disability compared to the WHS (2002) survey that covers the nationwide population. It seems reasonable, then, to adopt the calculated WHS (2002) prevalence rates in the multi-state model to project the number of elderly Malaysian according to their disability categories.

The calculated WHS (2002) prevalence rates from Tables 4.2 and 4.3 show that the able rates decrease as age increases and the disability prevalence rates gen-



(a)

Figure 4.1: A comparison between the estimated WHS (2002) disability prevalence rates (solid lines) and the published Kuala Langat disability prevalence rates which conducted in year 1981 (dashed lines). We can see that both prevalence rates are approximately similar for people age 50 and below.

erally increase as age increases. These trends appear in both males and females. The increase in disability prevalence rates for both males and females is considerable for the severe group. For example, the rate more than triples between 50 to 55 and 75 to 80. In comparison to males, female prevalence rates for mild, moderate and severe categories are higher for age 50 years and above, but lower for ages below 50.

Next, we will describe data used to perform the economic evaluation of long term care programs. This paper adopts cost utility analysis, which measures costs per QALY. Costs data from the budget announced by the minister were used in the numerator[5]. For calculating QALY, in order to be consistent with the EQ-5D instrument, we use the same WHS (2002) data but include more questions. The EQ-5D is a generic measurement of health-related quality of life which includes five dimensions: mobility, self-care, usual activities, pain and discomfort and anxiety and depression. Each of the dimensions has three levels including "no problems", "some problems" and "major problem". Questions that we chose to represent the corresponding five dimensions are as below.

[5]We used the report from the minister of Women, Family and Community, Datuk Heng Kai See, in 2012, government spent MYR$26.79 millions (USD$6.49 millions) for public residential care for elderly and MYR$5.8 millions (USD$1.41 millions) for public nursing home care (Bernama 2012).

- q2010: "Overall in the last 30 days, how much difficulty did you have with moving around?",
- q2020: "Overall in the last 30 days, how much difficulty did you have with self care, such as washing or dressing yourself?",
- q2060: "Overall in the last 30 days, how much difficulty did you have with personal relationship or participation in the community?",
- q2030: "Overall in the last 30 days, how much of bodily aches or pains did you have?",
- q2090: "Overall in the last 30 days, how much of a problem did you have with feeling sad, low or depressed?".

All five answers were combined to get an individual's EQ-5D health state. For example, if someone answered 1 for all questions, then his EQ-5D state was 11111—that means he was in a full health state with no problem for all five dimensions. A person with health state 21111 had some difficulties with mobility but otherwise no problems. The five dimensional health state is then transformed into an index referred to as the health related quality of life (HRQoL) or health utility score. This score acts as a direct measurement of an individual's overall health and referred to as QALYs. The method to calculate the health utility score will be described in detail in section 4.5.

4.4 Projection of elderly Malaysians by disability category

4.4.1 Multiple state model

The estimation of transition probabilities between several disability states followed the multiple state modelling framework from Rickayzen and Walsh (2002). Some formula and parameters were adjusted accordingly to suit Malaysian data. The model was applied to Malaysian prevalence rate of disability segregated according to age, gender and disability levels.

We included four disability states, namely able, mild, moderate and severe, and one absorbing state, death, in the model. Each disability state was denoted by j: j=0 to 3, where 0 represented the able/healthy state, 1 was mild, 2 was

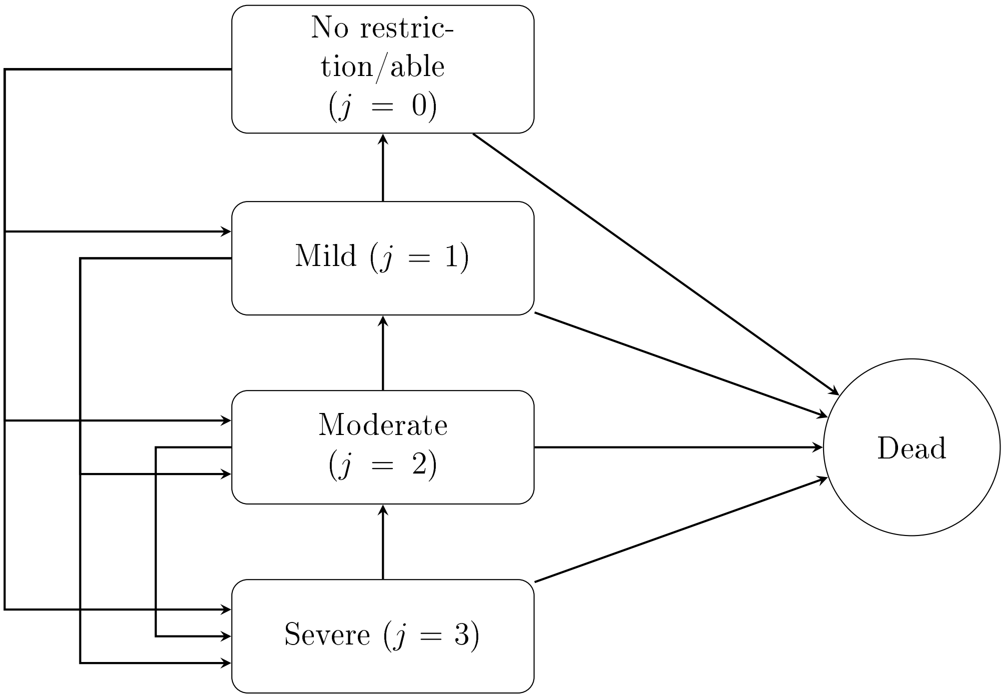


Figure 4.2: The multiple state model of disability for the Malaysian population. The model includes four disability states, including able, mild, moderate and severe, and one absorbing state, which is dead. Deterioration from current disability state is allowed to any state as shown in the diagram, whereas improvement from a current disability state is allowed to the next less severe category.

moderate and 3 was severe. There were three types of transition probabilities in the multiple state model, including death probabilities, deterioration probabilities (probabilities of moving to any worse disability state) and improvement probabilities (probabilities of recovering to a less disabled state or able state). Similar to Rickayzen & Walsh (2002), Leung (2004) and Hariyanto et al. (2013), the following assumptions were adopted in the model: 1. Deterioration to any worse disability state was allowed over a year, 2. Improvement was only allowed by one category, 3. Only one transition was possible over a one year period. The probabilities of transitions between the four states which occur within a year are described in Figure 4.2, the values of those probabilities are given in Appendix 4.A.

4.4.2 Model fit

The multiple state model comprises three types of probabilities: death, deterioration and improvement. The deterioration probabilities required the estimation of unknown parameters, whereas death and improvement probabilities were determined separately and included as an input in the fitting process (Hariyanto et al. 2013).

The deterioration probabilities were split into two parts. The first part is the probability that a healthy person becomes disabled and the second is the probability that a disabled person deteriorates to a more severely disabled state. See Section 4.4.4 for the formulation of deterioration probabilities. It is noteworthy that, the parameters of the deterioration probabilities were estimated through the fitting of the functional deterioration probability models, in which the model's prevalence rates were assumed to match the estimated WHS prevalence rates reported in Tables 4.2 and 4.3, as well as possible. We assumed stationary population characteristics when deriving transition probabilities. Similar to Leung (2004), the optimisation procedure available in Excel's Solver function was adopted for the fitting process. The sum of the squared difference of the WHS prevalence rates and the model's prevalence rates were minimised. Tables 4.4 and 4.5 present the difference between the two sets of prevalence rates which are expressed in percentage terms.

We can see from the Tables 4.4 and 4.5 that the percentage errors for males and females appear relatively small across almost all ages and disability states. Higher errors can only be seen for females aged 70 years old and above. This result is consistent with Leung (2004) who found poor fit for age 85 and above for Australian data. Figure 4.3 presents further comparison between the data and the fitted model. The model prevalence rates and the data prevalence are generally close to each other, particularly for the able, mild and severe categories. For the moderate level, we can see that the model's rates could not match the fluctuating observed trends that occurs at later ages.

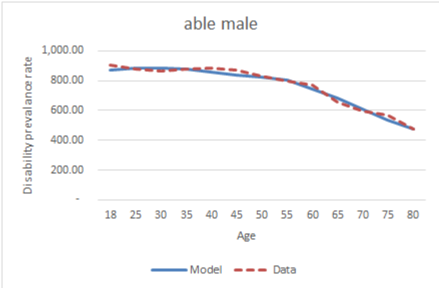
Note that the model's prevalence rates in Figure 4.3 are obtained after we fitted the model and determined parameters. The mathematical formulae used to estimate the probability of death, probability of deterioration and probability of improvement are discussed in the next section.

Table 4.4: The difference between the calculated WHS (2002) Malaysian disability prevalence rate and the model's prevalence rates for males, (data minus model as a percentage). The model provides a good fit for males with the percentage of the differences between the two rates being relatively small, less than 5% for all age groups and disability levels.

Age	Able	Mild	Moderate	Severe
18	3.42%	–1.91%	–0.99%	–0.52%
25	–0.78%	1.27%	–0.12%	–0.38%
30	–1.65%	1.25%	0.34%	0.05%
35	–0.06%	0.83%	–0.22%	–0.55%
40	2.19%	–0.97%	–1.04%	–0.18%
45	3.29%	–3.29%	–0.01%	0.01%
50	0.70%	0.00%	–0.22%	–0.48%
55	–0.08%	–0.77%	0.52%	0.37%
60	2.77%	–3.09%	0.25%	0.07%
65	–2.23%	1.44%	0.66%	0.12%
70	–1.67%	0.83%	2.04%	–1.20%
75	3.56%	–0.04%	–3.29%	–0.22%
80	0.19%	0.01%	–2.32%	2.05%

Table 4.5: The difference between the calculated WHS (2002) Malaysian disability prevalence rates and the model's prevalence rates for females, (data minus model, as a percentage). The percentage difference between the two sets of rates is relatively small, less than 5% for all age groups and disability levels, except for the oldest old age group.

Age	Able	Mild	Moderate	Severe
18	4.89%	–2.14%	–2.11%	–0.60%
25	1.87%	–0.39%	–1.03%	–0.45%
30	–1.31%	1.35%	0.26%	–0.30%
35	0.33%	0.22%	0.00%	–0.55%
40	1.81%	–0.01%	–1.65%	–0.15%
45	3.39%	–3.89%	0.17%	0.33%
50	0.56%	–0.01%	0.29%	–0.84%
55	2.60%	–2.89%	–0.29%	0.59%
60	1.63%	–0.90%	–0.37%	–0.36%
65	–6.10%	4.53%	–0.01%	1.59%
70	–2.90%	0.58%	3.40%	–1.08%
75	–4.32%	8.29%	–1.18%	–2.79%
80	6.87%	–0.44%	–6.43%	0.00%



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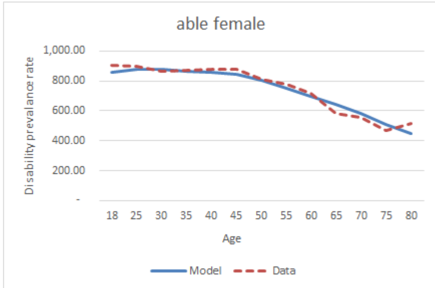

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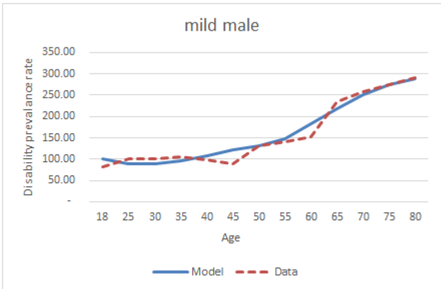

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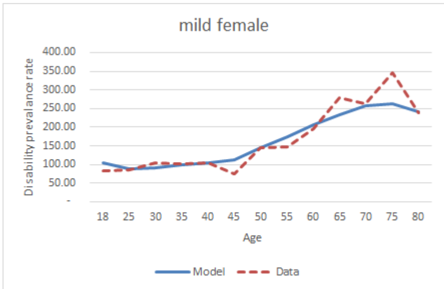

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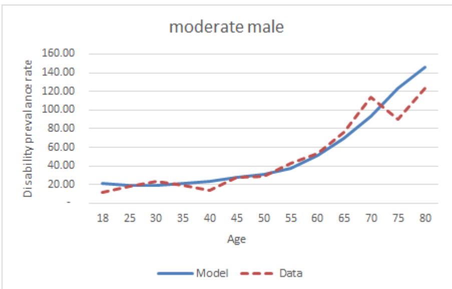

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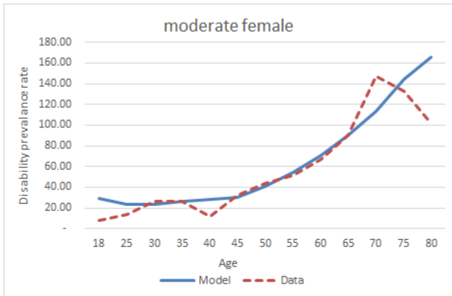

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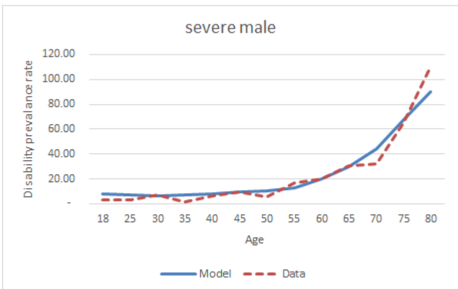

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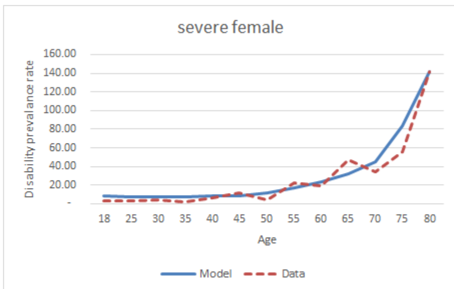

(h)

Figure 4.3: The comparison between the calculated WHS disability prevalence rates (dashed red lines) and the model's prevalence rate (solid blue lines). The model produces prevalence rates that are generally close to the data prevalence rates, especially for able, mild and severe disability levels for both genders. For the moderate level, the model overestimates rates, compared to the data, at the oldest old ages.

4.4.3 The probability of death

The probability of death can be divided into two categories, overall mortality, $Overall_{mort}$ together with additional mortality, $Additional_{mort}$. The overall mortality assumes that people who are in the same age group and gender will experience the same mortality, regardless of their level of disability. Additional mortality imposes an extra rate on those who are in the severe disability category ($j = 3$), that means the mortality rates of disabled people gets higher as disability status becomes more severe. The probability of death is given as follows,

$$Mort(x + 0.5, j) = Overall_{mort}(x + 0.5) + Additional_{mort}(x + 0.5, j), \quad (4.1)$$

where $Mort(x, j)$ is the one-year death probability that applies to an individual aged x in disability state j ($j = 0, 1, 2, 3$). The $Overall_{mort}(x)$ is the one-year death probability which applies to any individual aged x regardless of his/her disability status. These probabilities were obtained from the Department of Statistics Malaysia (2002). The $Additional_{mort}(x, j)$ is the one year additional probability imposed on people who are in the severe disability state $j = 3$ and is given by,

$$Additional_{mort}(x, j) = \frac{M}{1 + 1.1^{50-(x+05)}} \times \frac{\max(j - 2, 0)}{2}. \quad (4.2)$$

where M is the maximum additional annual mortality imposed on severely disabled persons. There is a little known about the impact of disability on mortality in Malaysia throwing up some uncertainties regarding M. Rickayzen & Walsh (2002) used $M = 0.2$ for the UK population whereas Leung (2004) used $M = 0.15$ for Australia, followed the value suggested by Society of Actuaries Long-Term Care Valuation Insurance Methods Task Force (1995). Due to the limited information regarding the relationship between the disability and death in Malaysia we used M values from Hariyanto et al. (2013) for Australia which are M of 0.11 for males and 0.08 for females. Nonetheless, the M values from Hariyanto et al. (2013) are increased by 40% as we assume death in the severe disability category in Malaysia is higher than Australia. Thus, the M values adopted for Malaysia are 0.154 for males and 0.112 for females.

Table 4.6: The estimated parameters for $New_{disabled}(x)$ formula for males and females

Parameter	Males	Females
α	0.7888	0.8153
A	0.0097	0.0007
B	1.0598	1.0452
C	98.1510	109.3219
D	0.5382	0.6472
E	52.0239	42.9881

4.4.4 The probability of deterioration

Deterioration is defined as the transition from any current state to any worse disabled state. The estimation of deterioration probabilities includes two types of deterioration. First, a healthy person becomes disabled, denoted as $Deteriorate(x, 0, j)$ and second, a disabled person deteriorates to a more severely disabled state, denoted as $Deteriorate(x, m, n)$.

The formula for the first, which is the probability a healthy person ($j = 0$) aged x deteriorates to any disability category j ($j = 1, 2, 3$), comprises two components, expressed as below

$$Deteriorate(x, 0, j) = New_{disabled}(x) \times Severity(x, j). \tag{4.3}$$

The first component, $New_{disabled}(x)$, represents the probability a healthy person aged x becoming disabled for the first time, which can be estimated as follows

$$New_{disabled}(x) = \alpha \left[\left(A + \frac{D - A}{1 + B^{C-x}} \right) \times \left(1 - \frac{1}{3} \exp \left(- \left(\frac{x - E}{4} \right)^2 \right) \right) \right] \tag{4.4}$$

For Malaysian data, we apply the same formula for both males and females. According to Rickayzen & Walsh (2002), A is the limit of probability of becoming disabled at young ages and D is the limit of probability of becoming disabled that would apply at extremely old ages. Parameters B and C determine how rapidly the probabilities change between the two extreme values, A and D. Age E identifies the kink in the new disabled rates after which disability rates increase dramatically. The estimated parameters for equation (4.4) are given in Table 4.6.

The second component, $Severity(x, j)$, is the probability that a healthy person aged x deteriorates to a particular disabled state given that he becomes disabled

Table 4.7: The estimated parameters for $Severity(x, j)$ formula for males and females

Parameter	Males	Females
F	0.4110	0.4221
G	1.0824	1.5060
H	81.5673	78.2006
$W(1)$	0.9654	0.9621
$W(2)$	0.3741	0.4287
$W(3)$	0.3342	0.2566
I	2.0998	3.7592

over the year. The formula for $Severity(x, j)$ is

$$Severity(x, j) = \frac{W(j) \times f(x)^{j-1}}{Scale(x)} \tag{4.5}$$

$$f(x) = P + \frac{1 - P}{1 + Q^{R-x}} \tag{4.6}$$

$$Scale(x) = \sum_{j=1}^{3} W(j) f(x)^{j-1} \tag{4.7}$$

where $W(n)$ are category widths designed to allow for some categories having more people than others. Variables P, Q and R reflect the age-dependence of disability and $Scale(x)$ ensures the probabilities sum to one.

The second type of deterioration probability, after that discussed in equation (4.3), is $Deteriorate(x, m, n)$, which is the probability that a disabled person in disability state m becomes more severely disabled—moves to state j, $j > m$—as follows,

$$Deteriorate(x, m, j) = Deteriorate(x, 0, j) \times I^m. \tag{4.8}$$

Equation (4.8) shows that the probability of a person at disability level m deteriorating to level j ($j > m$) is I^m times the probability of that person from the healthy state deteriorates to disability level j. The parameter values for severity are presented in Table 4.7.

Table 4.8: Improvement Rates

Improvement from	**mild to able**	**moderate to mild**	**severe to moderate**
Recovery rate	15.0%	15.0%	12.50%

4.4.5 The probability of improvement

As in Rickayzen & Walsh (2002), Leung (2004) and Hariyanto et al. (2013), our multiple state model includes the probability that a person who is disabled can improve his disability condition to a less severe state or the able state. A simple assumption has been adopted in which the improvement in disability is allowed to only one less severe category over a year—if and only if he survives and does not deteriorate to a more severe disability state.

Rickayzen & Walsh (2002) used a constant of 10% as the improvement rate for every disability category over the period of a year. This paper, however, follows Leung (2004) in allowing a variable chance of improvement from different disability states as in Table 4.8.

4.4.6 Projection method

Once the transition probabilities for the model were estimated, the Malaysian population including disability categories (that is, able, mild, moderate and severe) were projected up to year 2040. Of particular interest were the results for 2030, when Malaysia is expected to become an aged nation (Goh & Lai 2013, Mahari 2011).

The Department of Statistics Malaysia *DoSM* has produced official population projections up to year 2040 (Hassan 2012). However, none of those projections are segregated according to disability levels and so the initial numbers in each disability category are lacking. In order to begin the projections, the initial number of population in each category is estimated in such that the male and female disability prevalence rates of the model year 2002 are multiplied by the *DoSM* age-group total of males and females of the same year. Although the model prevalence rates are not fully consistent with the data prevalence rates, the differences are assumed to be minimal (Leung 2004).

4.4.6.1 International migration

We adopt the *DoSM*'s projection assumptions regarding international migration in projecting the Malaysian population by disability levels. According to Hassan (2012), Malaysian population projections from 2010 to 2040, do not account for in-migration and out-migration of Malaysian citizens due to data limitations. Therefore, for consistency with this official projection, no migration component will be included in our projection model.

4.4.6.2 Mortality improvement

The mortality rates used in this projection are based on Malaysian life tables 2002. However, in estimating the mortality improvement over the years, this paper extends the Leung (2004) projection method to account for two different types of mortality improvement as follows.

<u>Method 1: Reduction Factor</u>

The first method is similar to Leung (2004) and Bueno (2013) which adopt the reduction factor formula from the Continuous Mortality Investigation Bureau (1999) of the Institute and Faculty of Actuaries, given as

$$q(x,t) = q(x,0) \times RF(x,t), \tag{4.9}$$

where $RF(x,t)$ is the reduction factor for age x at time t. This reduction factor decreases the mortality rates exponentially towards a limiting value,

$$RF(x,t) = \alpha(x) + [1-\alpha(x)] \times [1-f(x)]^{\frac{t}{20}}, \tag{4.10}$$

where

$$\alpha(x) = \begin{cases} c & \text{for } x \le 65 \\ 1 + (1-c) \cdot \frac{(x-125)}{65} & \text{for } x > 65 \end{cases} \tag{4.11}$$

and

$$f(x) = \begin{cases} h & \text{for } x \le 65 \\ \frac{(125-x)\cdot h + (x-65)\cdot k}{65} & \text{for } x > 65 \end{cases} \tag{4.12}$$

The parameters c, h and k are estimated based on the death component's as-

Table 4.9: The estimated parameters of the mortality reduction factor for males and females

Parameter	Males	Females
c	0.175	0.176
h	0.441	0.428
k	0.391	0.391

sumption of the *DoSM's* projection in which life expectancy at birth of males and females increases by 0.2 years per year. Thus, the parameters are calculated such that the mortality rates decrease to reach a certain value which will result in the life expectancy at birth of 78 years and 83 years for males and females in 2040. The estimated parameters are shown in Table 4.9. Note that the complete life expectancy at birth is estimated using the standard life table approach as follows

$$e_x = \frac{1}{l_x} \cdot \left\{ \sum_{y \leq x} l_y - \frac{l_x}{2} \right\}. \tag{4.13}$$

Method 2: The product-ratio coherent approach

Another way to estimate mortality improvement is to use the product-ratio coherent model from Hyndman et al. (2013). This model evolved from the original Lee & Carter (1992) modelling framework which makes use of observed time-series data in estimating future mortality improvement or trends. The product-ratio model has been successfully applied to both Australia and Malaysia and was shown to forecast these countries' mortality more accurately the Lee & Carter (1992) model and other independent models (Hyndman et al. 2013, Shair et al. 2015). Using this approach, two or more sub-populations' morality rates are combined and jointly forecast to generate non-divergent forecasts between sub-populations over the long run. Sub-populations can be grouped together by gender, ethnicity, state and countries.

We use a developed-developing countries coherence to estimate mortality improvement for elderly Malaysian. This type of coherency is applied to Malaysian mortality data due to past data has suggested that the mortality rates of high-mortality nations have been converging towards lower values at which most low-mortality countries have experienced in previous years (Wilson 2001). None of the mortality forecasting models so far has accounted for this developed-developing countries coherence. Thus, it is of interest to this study to use this method to estimate the mortality improvement among disabled elderly Malaysian, using a low-mortality country, Australia, as reference.

Thus, Australian male and female mortality should be good reference rates for Malaysian male and female mortality. The two sub-populations' mortality rates were combined using the product and ratio functions below,

$$p_{x,t} = \left[\prod_{i=1}^{I} f_{x,t,i}\right]^{\frac{1}{I}} \tag{4.14}$$

and

$$r_{x,t,i} = \frac{f_{x,t,i}}{p_{x,t}}, \tag{4.15}$$

where $i = 1, 2 \ldots, I$ are the number of sub-populations under consideration and $f_{t,i,x}$ the smoothed age-specific mortality rates for the i^{th} population. As a smoothing procedure, Hyndman et al. (2013) use weighted penalised regression splines. A monotonic increasing constraint over time is imposed at age x and above. The product function $p_{x,t}$ is calculated as the geometric mean of the smoothed rates of the sub-populations which yields the general trend of the sub-populations. The ratio $r_{t,i,x}$ of one sub-population's rates to the geometric mean and itself represents the mortality difference of a particular sub-population with the general trend. The details of the method are given in Hyndman et al. (2013).

4.4.6.3 The projection model

Below we outline the method used to project the age-sex-specific population by disability levels. We use Rickayzen & Walsh (2002), but omit the migration component.

Define $Lives(x, t, n)$ as the number of lives aged x in year t in disability category n. Then,

$$\begin{aligned} \textit{Lives(x,t,n)} = {} & [Lives(x-1,t-1,n)] \\ & \times [1 - Mortality(x-1,t-1,n)] \\ & \times [1 - Deteriorate\_From(x-1,t-1,n)] \\ & \times [1 - Improve\_From(x-1,t-1,n)] \\ & + Deteriorate\_To(x,t,n) + Improve\_To(x,t,n) \end{aligned} \tag{4.16}$$

where $Mortality(x,t,n)$ is the probability that a person aged x at time t and with disability category n dies in the following year defined as below

$$Mortality(x,t,n) = q(x,t) + Additional\_Mortality(x,t,n), \tag{4.17}$$

and $Deteriorate\_From(x,t,m)$ is the probability that a person aged x at time t and with disability category m makes a transition to a more severe disability category. Thus,

$$Deteriorate\_From(x,t,m) = \sum_{n=m+1}^{3} Deteriorate(x,t,m,n). \tag{4.18}$$

Also $Improve\_From(x,t,n)$ is the probability that a person, who does not deteriorate to a more severe disability category, improves by one category. Thus,

$$Improve\_From(x,t,n) = \begin{cases} 0.15 & \text{for } n = 1,2 \\ 0.125 & \text{for } n = 3. \end{cases} \tag{4.19}$$

Further, $Deteriorate\_To(x,t,n)$ is the number of persons aged x at time t who make a transition to disability category n from a less severe disability category. Thus,

$$\begin{aligned} Deteriorate\_To(x,t,n) = {} & \sum_{m=0}^{n-1} [Lives(x-1,t-1,m)] \\ & \times [1 - Mortality(x-1,t-1,m)] \\ & \times Deteriorate(x-1,t-1,m,n). \end{aligned} \tag{4.20}$$

Finally, $Improve\_To(x,t,n)$ is the number of persons aged x at time t who makes a transition to disability category n from a more severe disability category $n+1$. Thus,

$$\begin{aligned} Improve\_To(x,t,n) = {} & [Lives(x-1,t-1,n+1)] \\ & \times [1 - Mortality(x-1,t-1,n+1)] \\ & \times [1 - Deteriorate\_From(x-1,t-1,n+1)] \\ & \times Improve\_From(x-1,t-1,n+1). \end{aligned} \tag{4.21}$$

4.4.6.4 Disability improvement

In addition to mortality improvement, the projection method is also developed to allow improvements in disability over the years. In line with Leung (2004), three types of disability improvements will be included in the model—improvement in the incidence of disability, improvement in severity and deterioration.

<u>Improvement in the incidence of disability</u>

The improvement factor for the incidence of disability will be estimated using the same method of the first type of mortality improvement we consider which is the reduction factor method. The second method of mortality improvement could not be applied to disability due to the absence of time-series of disability data for Malaysia. The reduction factor formula for disability is defined as follows

$$New\_disabled(x,t) = New\_disabled(x,0) \times RF(x,t), \tag{4.22}$$

where $RF(x,t)$ is the reduction factor for age x at time t. This reduction factor decreases the disability rates exponentially towards a limiting value.

$$RF(x,t) = \alpha(x) + [1-\alpha(x)] \times [1-f(x)]^{\frac{t}{20}}, \tag{4.23}$$

where

$$\alpha(x) = \begin{cases} c & \text{for } x \le 65 \\ 1 + (1-c) \cdot \frac{(x-110)}{65} & \text{for } x > 65 \end{cases} \tag{4.24}$$

and

$$f(x) = \begin{cases} h & \text{for } x \le 65 \\ \frac{(110-x)\cdot h + (x-65)\cdot k}{65} & \text{for } x > 65 \end{cases} \tag{4.25}$$

Table 4.10: The scenarios and parameters for the improvement in the incidence of disability for males

Scenarios	Maximum Reduction in Incidence at 2040 for age 65	c	h	k
low	5%	0.257	0.076	0.391
medium	10%	0.224	0.148	0.391
high	15%	0.205	0.223	0.391

Table 4.11: The scenarios and parameters for the improvement in the incidence of disability for females

Scenarios	Maximum Reduction in Incidence at 2040 for age 65	c	h	k
low	5%	0.241	0.070	0.300
medium	10%	0.212	0.146	0.300
high	15%	0.110	0.197	0.300

The $\alpha(x)$ and the $f(x)$ formula are slightly different to that of mortality improvement due to the assumption that improvement in the incidence of disability is less likely to be as great as mortality improvement (Leung 2004). Due to uncertainty on the magnitude of improvement in the incidence of disability, three scenario are tested for sensitivity. Refer to Tables 4.10 and 4.11 for the scenarios and their corresponding parameters for males and females respectively. It is apparent that, under the low scenario, the probability of new incidence of disability at age 65 reduces gradually until year 2040, the time when the probability of transition is reduced by 5% from the probability in 2002.

Improvement in severity and deterioration

Another type of improvement that is accounted for in projecting the number of people according to their disability levels is severity improvement. This type of improvement will reduce the probability of transitions to higher disability states from an initially able state. The formula is as below

$$f(x,t) = f(x,0) \times \beta^t, \tag{4.26}$$

Table 4.12: The scenarios and parameters for improvement in severity

Scenarios	β
low	0.999
medium	0.998
high	0.997

Table 4.13: The scenarios and parameters for improvement in deterioration

Scenarios	α
low	0.99
medium	0.98
high	0.97

where $f(x,t)$ is as per equation (23) with time dependence. The scenarios for improvement in severity is presented in Table 4.12.

The last type of improvement is the improvement in the deterioration from one disability level to any one of the more severe levels. This type of probability need to be accounted for due to improving medical technologies and resources over the years, which has resulted in reducing the severity conditions of individuals who are already disabled. Similar to Rickayzen & Walsh (2002), the formula that was used for the improvement in deterioration was as follows,

$$I(t) = 1 + [I(0) - 1] \times \alpha^t. \tag{4.27}$$

The α values are given in Table 4.13 to represent the scenarios of improvement in deterioration.

Our projection of elderly Malaysian which include disability categories will account for a range of improvements in mortality, incidence of disability, severity and deterioration, and leads to the series of projections described in Table 4.14.

Table 4.14: The population projection scenarios

Scenarios	Mortality Improvement	Incidence of disability improvement	Severity Improvement	Deterioration Improvement
A	method 1	low	low	low
B	method 1	medium	medium	medium
C	method 1	high5	high	high
D	method 2	medium	medium	medium
E	method 1	constant	constant	constant
F	method 2	constant	constant	constant

4.5 Cost utility analysis of Malaysian public long term care for the elderly

We extend Leung (2004) to include an economic evaluation of the Malaysian public long term care programs. The economic evaluations of the two different types of institutional care are performed to identify the effectiveness of the programs in improving the quality of life of residents. We use a cost utility analysis (CUA) approach to achieve this objective,

$$CUA = \frac{Costs}{QALY} \tag{4.28}$$

where $Costs$ is the average yearly government expenditure spent for a stay in either residential care or nursing home care. Because these public long term care institutions are fully funded by government, the average yearly costs of the programs such item as beds, medicines, food, activity of daily livings include assistance, and much more. The denominator of the formula, $QALY$, represents the average quality adjusted life year which is a preference-based health measure comprising both length and health-related quality of life (*HRQoL*). Specifically, QALYs is defined as

$$QALYs = \textit{Life time spent in the current health state} \times \textit{HRQoL} \tag{4.29}$$

Since the $QALY$s of the elderly living in the institutions are measured during their stay in a year, the *Life spent in current health status* for each individual is set to one year, reducing the formula of $QALY$s to just the *HRQoL*. The

HRQoL is an index, which is a single number representing the overall level of an individual's healths. This index ranges from 0 (the worst health status) to 1 (perfect health status)

One well known instrument to construct *HRQoL* index is EQ-5D. The EQ-5D is a generic based instrument which was originally developed in Europe by the The EuroQol Group (1990). This instrument is now used worldwide. The EQ-5D focuses on five dimensions that describe the *HRQoL*, including mobility, self-care, usual activities, pain or discomfort and anxiety or depression. Each dimension has three levels: "no problem", "some problems" and "major problems". The three levels in each of the five dimensions yield $3^5 = 243$ possible health states, which are identified by a five digit code. For example, the EQ-5D state 21111 would mean an individual is having some problem in mobility and no problem with self-care, usual activities, pain and depression. We can see easily from this five-digit indicator that a person with state 21111 is experiencing worse health than a person with state 11111, because the first has some problem with his mobility whereas the second is in the perfect health. Nonetheless, it is sometimes difficult to judge the health status between two different states. For instance, it is hard to say that 21111 state is better than 12111, or vice-versa because the later has some difficulties in self-care instead of mobility. Therefore, an index is required to represent the overall level of health of an individual.

There are three methods that are frequently used for eliciting the index, namely a visual analogue scale (VAS), a standard gamble (SG) or time trade-off (TTO). We chose the EQ-5D value set elicited using the TTO approach, as in Yusof et al. (2012). The TTO elicitation equation developed by Yusof et al. (2012) was based on a Malaysian sample and is defined below

$$\begin{aligned} HRQoL = 0.863 &- 0.039 \times \text{Mobility level 2} - 0.08 \times \text{Mobility level3} \\ &- 0.061 \times \text{Self-care level 2} - 0.083 \times \text{Self-care level 3} \\ &- 0.03 \times \text{Usual activities level 2} - 0.04 \times \text{Usual activities level 3} \\ &- 0.09 \times \text{Pain level 2} - 0.14 \times \text{Pain level 3} \\ &- 0.051 \times \text{Depression level 2} - 0.043 \times \text{Depression level 3} \\ &- 0.13 \times N3 \end{aligned} \tag{4.30}$$

The regression equation above was estimated using levels 2 and 3 in each of the EQ-5D dimensions as a dummy variable, taking the value of 1 if they exist and 0 otherwise. The $N3$ variable takes the value 1 if the health state consists of level 3 in any of the dimensions. For example, the health state 11213 would translate to $0.863 - 0.03 - 0.043 - 0.13 = 0.66$.

We did not directly conduct an EQ-5D survey to obtain the five-digit health state of the elderly living in public institutional long term care—this would involve a large survey study. Instead, we employed the WHS survey data, choosing questions that were relevant to the EQ-5D and assumed these responses were representative of those residing in the government sponsored long term care facilities. Further details on how we derived the five-digit health state were given in section 4.3.

4.6 Findings

4.6.1 Future elderly Malaysian by disability levels

The following results present six different population projection scenarios (A to F) of the elderly Malaysians according to their disability levels. See Table 4.14 for the assumptions used in each scenario.

Scenarios A, B and C of the population projections are based on low, medium and high assumptions of mortality improvement, incidence of disability improvement, deterioration and severity improvement. We added scenario D, which applied a different method of estimating mortality. Hence, the effect of using the two different methods of mortality improvement can be estimated if we compare Scenarios D and B. For Scenarios E and F, we assume that there is no improvement in disability, therefore the projections are merely based on mortality improvements.

The results of the projected elderly Malaysian by gender and disability categories are discussed next. In term of overall (average between six scenario projections), Table 4.15 shows the projected mildly and moderately disabled elderly will increase substantially, 2.8 times the 2010 value for males and 2.5 times for females by 2030. This group of people will further increase to more than triple the 2010 value for males and females by 2040. At the time that Malaysia is expected to become an aged nation, in 2030, the number of disabled elderlies with mild and moderate disability levels will represent 29% and 31% of the Malaysian male and female elderly, respectively. These elderly are assumed to require low levels of long term care in the future. Table 4.16 shows the projected elderly Malaysian in the severe category. This group of people is assumed to be those needing high level of care or nursing home care. In overall term, the severely disabled male elderly are projected to increase more substantially than the mild and moderate disabled elderly, that is, to increase 3.1 times from 23,206 in 2010 to 71,946 in 2030 for males. For females, the severely disabled increase 2.5 times from 29,731 in 2010 to 73,620 in 2030. By 2040, the number of severely disabled elderly swells to more than quadruple for males and triple for females, respectively. These severely disabled elderly will represent 3% of the elderly population for both genders in 2030. In short, these overall results suggest the Malaysian disabled elderly is expected to significantly increase for all disability categories: mild, moderate and severe, and for both males and females. One factor contributing to this change is the improvement in the observed Malaysian mortality. As disability is profound among older aged people, an increase in the elderly population results in a growing number of the disabled elderly.

Next, comparisons between the six projection scenarios are made. Comparing scenarios A, B and C (low, medium and high disability improvement assumptions) shows that the low assumption of disability improvement in Scenario A yields a higher number of disabled male and female elderly than that of Scenarios B and C. This outcome indicates that the projection model has successfully captured the effect of disability improvements on the change in the disabled elderly population. Scenarios A, B and C are based on the same mortality improvement assumption (method 1), thus the change in population projection is affected by disability improvement, including the incidence of disability improvement and the deterioration and severity improvements.

The effect of different mortality improvement assumptions on the projection of disabled elderly can be identified if we compare scenario B with D. While we use the reduction factor approach (method 1) in scenario B, the time-series extrapolation method that accounts for the coherency between developed and developing countries (method 2) is adopted in scenario D. Results show scenario D consistently produces slightly higher projection numbers than that of scenario B for males and females and for each of the disability categories: mild, moderate and severe. The reason why the method 2 approach to mortality improvement produces higher population projections than that of method 1 is because the method is influenced by Australian male and female mortality in estimating Malaysian male and female mortality. Hence, the improvement in Malaysian mortality is

Table 4.15: The projected number of mildly and moderately elderly Malaysian aged 60 years and above. The projection numbers increase over the forecast years. Scenario C produces the least projection numbers for both genders. Scenario F produces the largest population for males, whereas scenario E does this for females.

Male				
Scenarios	**2010**	**2020**	**2030**	**2040**
A	221,233	404,336	620,494	803,976
B	220,197	396,963	600,914	768,068
C	201,496	362,729	548,944	694,192
D	220,259	397,856	606,265	778,859
E	222,435	412,688	643,236	846,904
F	222,506	413,677	649,016	858,504
Average	218,021	398,042	611,478	791,751
Female				
Scenarios	**2010**	**2020**	**2030**	**2040**
A	282,272	492,337	748,236	948,723
B	281,281	482,727	720,396	897,370
C	274,739	391,065	512,552	610,534
D	282,132	490,745	738,041	932,197
E	283,762	507,211	792,355	1,034,099
F	283,687	505,991	782,875	1,018,626
Average	281,312	478,346	715,743	906,925

Table 4.16: The projected number of severely disabled elderly Malaysian aged 60 years and above. The projection numbers increase over the forecast years. Scenario C produces the least projection numbers for both genders. Scenario F produces the largest population for males, whereas scenario E does this for females.

Male				
Scenarios	**2010**	**2020**	**2030**	**2040**
A	23,574	44,604	73,129	98,934
B	23,027	41,636	65,733	86,315
C	21,163	37,024	57,404	74,160
D	23,036	41,726	66,342	87,721
E	24,223	48,588	84,923	122,158
F	24,213	48,478	84,142	120,216
Average	23,206	43,676	71,946	98,251
Female				
Scenarios	**2010**	**2020**	**2030**	**2040**
A	29,703	46,446	67,446	82,372
B	28,410	40,911	55,996	66,058
C	25,345	29,756	35,794	42,583
D	29,668	46,126	66,136	80,371
E	32,622	61,913	107,279	154,068
F	32,637	62,225	109,067	157,252
Average	29,731	47,896	73,620	97,110

expected to follow Australian mortality—that is, continue decreasing and converging towards a low level. Unfortunately we cannot compare whether method 2 is more accurate than method 1 because, to the best of our knowledge no projection by disability status has been published by the *DoSM* or other agency. Nevertheless, the findings from Shair et al. (2016) indicate that method 2 can outperform other methods when forecasting the Malaysian male and female population.

Moreover, we include control scenarios E and F in which disability is assumed constant throughout the forecast years. We use the same disability prevalence rates from 2002. Mortality improvement is included in these control models by adopting method 1 and method 2 in scenarios E and F, respectively. As a result of these assumptions, the change in the future population is solely based on mortality improvement. The results in Tables 4.15 and 4.16 show that these two projection scenarios lead to a considerably higher number of disabled elderly males and females for all disability categories. This result highlights the importance of medical innovation and advancement, particularly in reducing the incidence of disability and the chance of disabled elderly deteriorating to a more severely disabled status. Reducing the likely number of disabled elderly indirectly will reduce the demand and, ceteris paribus, the costs of providing long term care.

Although we cannot compare our projected population by disability levels with an official projection from the *DoSM* we can compare our results with those of the *DoSM* in the case of the total elderly population—which is the summation of the projected elderly in the able, mild, moderate and severe categories. Table 4.17 presents this comparison. The projected total number of elderly increase over the forecast years for all scenarios, males and females, and the *DoSM* projection falls within the scenario ranges for years 2030 and 2040.

4.6.2 Future demand and costs of long term care

The Malaysian public long term care is a fully funded government program consisting of both residential care (RC) and nursing home care (NH). Residential care provides care and services only for those elderly who are independent and require low levels of care, whereas nursing home care is for those who are severely disabled and dependent on professional care most of the time.

The percentage of the elderly population who are entitled to the Malaysian

Table 4.17: The projected total number of elderly Malaysian aged 60 years old and above, which is the aggregated number of elderly in all states—able and mildly, moderately and severely disabled.

Male			
Scenarios	**2020**	**2030**	**2040**
A	1,456,597	2,193,969	2,832,532
B	1,457,282	2,195,565	2,834,350
C	1,326,575	2,034,735	2,635,198
D	1,461,165	2,214,879	2,868,354
E	1,459,651	2,211,146	2,863,830
F	1,455,772	2,191,869	2,829,912
Average	1,436,174	2,173,694	2,810,696
DoSM	1,535,100	2,085,100	2,765,800
Female			
Scenarios	**2020**	**2030**	**2040**
A	1,586,849	2,424,004	3,114,457
B	1,588,243	2,426,794	3,117,164
C	1,468,888	2,156,667	2,736,479
D	1,583,985	2,398,007	3,072,497
E	1,580,470	2,398,691	3,062,867
F	1,583,331	2,415,569	3,104,627
Average	1,565,294	2,369,955	3,034,682
DoSM	1,620,300	2,324,200	3,099,800

Table 4.18: The percentage of elderly living in public residential care (RC) and nursing home care (NH) in 2012 under the existing long term care policy. The percentage of RC and NH coverage was extremely small for both genders.

Residential Care (RC)	**Total**	**Male (60%)**	**Female (40%)**
Number of elderly in RC	1,847	1,108	739
DoSM total elderly projections	2,262,800	1,111,500	1,151,300
% of RC coverage under current long term care provision	0.082%	0.100%	0.064%
Nursing home care (NH)	**Total**	**Male (60%)**	**Female (40%)**
Number of elderly in NH	237	142	95
DoSM total elderly projections	2,262,800	1,111,500	1,151,300
% of NH coverage under current long term care provision	0.010%	0.013%	0.008%

public long term care programs was extremely small. According to the report from the Social Welfare Department, in 2012, there were 2,084 elderly people living in public institutions in total which 1,847 of them were living in the residential care and 237 were living in nursing home care. Out of these recipients, approximately 60% of them were males and 40% were females. As calculated in Table 4.18, these reported numbers have resulted in a small percentages of coverage for the public institutional care programs in Malaysia—0.082% of the aged for residential care and 0.010% for nursing home care. These percentages of coverage are assumed constant each year in estimating the demand for Malaysian public long term care, meaning no reform or modification of current provision is made throughout the forecast years.

The percentage of coverage of the public long term care programs (Table 4.18) multiplied by the overall[6] projected disabled elderly in Table 4.17, yield the likely number of elderly Malaysian requiring public long term care either residential

[6]The overall projected total elderly males and females were calculated as the mean of the six scenario projections.

Table 4.19: The projected number of elderly receiving residential care (RC). The expected number of people living in residential care is increasing over the years, with male residents consistently higher than that of female residents.

Male	**2020**	**2030**	**2040**
The overall projected elderly	1,436,174	2,173,694	2,810,696
Projected RC residents (0.100% of the projected overall elderly)	1,436	2,174	2,810
Female	**2020**	**2030**	**2040**
The overall projected elderly	1,565,294	2,369,955	3,034,682
Projected RC residents (0.064% of the projected overall elderly)	1,002	1,517	1,942

care or nursing home care—presented in Tables 4.19 for residential care and 4.20 for nursing home care. If we compare these two tables with the initial value in 2012, as in Table 4.18, we can see that the likelihood of residential care and nursing home care residents are expected to double by 2030. For example, the 2012 reported elderly Malaysian living in public residential care will increase from 1,108 to 2,174 and from 739 to 1,517 for males and females, respectively. Similarly, for public nursing home care, the number of severely disabled elderly requiring the service is also expected to increase from 142 to 263 for males and from 95 to 190 for females.

Given the estimated elderly requiring public residential care and nursing home care doubling by 2030, the future costs of these public programs are expected to increase accordingly. The costs of public long term care programs are calculated by multiplying the expected demand for public institutional care as in Tables 4.19 and 4.20 with the average costs per person staying in that institutions. It is noteworthy that comprehensive data for Malaysian long term care costs are not published and hence not available for public use. We use the reported total government spending on the public long term care programs in 2012—MYR$32.59 millions in which MYR$26.79 millions were spent on residential care and MYR$5.80 millions on nursing home care. Hence, in 2012, the average annual

Table 4.20: The projected number of elderly receiving nursing home care (NH). The expected number of people living in nursing home care is increasing over the years with male residents consistently higher than that of female residents.

Male	**2020**	**2030**	**2040**
Projected total elderly	1,436,174	2,173,694	2,810,696
Projected NH residents (0.013% of the projected total elderly)	174	263	340
Female	**2020**	**2030**	**2040**
Projected total elderly	1,565,294	2,369,955	3,034,682
Projected NH residents (0.008% of the projected total elderly)	125	190	243

costs per person for residential care AC_{RC} and nursing home care (AC_{NH}) are as below,

$$AC_{RC} = \frac{LTCC_{RC}}{\sum P_{RC}} = \frac{26,790,000}{1847} = \text{MYR}\$14,504 \tag{4.31}$$

$$AC_{NH} = \frac{LTCC_{NH}}{\sum P_{NH}} = \frac{5,800,000}{237} = \text{MYR}\$24,472 \tag{4.32}$$

where $LTCC_{RC}$ and $LTCC_{HH}$ are the total annual long term care costs for residential care and nursing home care. The P_{RC} and P_{NH} are the total number of resident who are living in residential care and nursing home care in 2012. The calculation above show that the average costs for nursing home care is significantly higher than that of residential care due to the greater intensity of care needed by those living in nursing home care compared to residential care. Furthermore, the majority of those living in nursing home care are suffering chronic illnesses, hence require extra medical care and assistance in daily living.

The total projected costs of public long term care programs: residential care and nursing home care are presented in Table 4.21. The average long term care costs per person, AC_{RC} and AC_{NH} are assumed constant throughout the projection years, hence the aggregate costs are dependent only on the projected number of elderly receiving public long term care. Results from Table 4.21 show the projected Malaysian public long term care costs are expected to double for both residential care and nursing home care by 2030. For instance, the total govern-

Table 4.21: The projected costs of elderly receiving residential care and nursing home care. Costs are in MYR$ millions. The costs of both public institutional care programs increases over time. Cost for male group is higher than female

Total public residential care costs			
	2020	**2030**	**2040**
Males	20.83	31.53	40.76
Females	14.53	22.00	28.17
Total	**35.36**	**55.53**	**68.93**
Total public nursing home care costs			
	2020	**2030**	**2040**
Males	4.26	6.44	8.32
Females	3.06	4.65	5.95
Total	**7.32**	**11.09**	**14.27**
Total public long term care costs			
	2020	**2030**	**2040**
Males	25.09	37.97	49.08
Females	17.59	26.65	34.12
Total	**42.68**	**66.62**	**83.20**

ment spending on residential care increases from MYR$26.79 millions in 2012 to MYR$51.99 million in 2030. For nursing home care, the costs increase from MYR$5.8 millions to MYR$11.19 millions over the same years. It is noteworthy that these projected costs are in real terms without taking into consideration inflation. In addition, we assume that existing government policy remained the same, that is, the same percentages of coverage as in Table 4.18 are applied in each year.

In terms of share of GDP, in 2012, the government spent MYR$32.59 millions on public institutional long term care, which represented 0.0035 per cent of GDP. This percentage is miniscule compared to the 4 per cent[7] spent on health care in the same year. By 2030, the projected public long term care costs are expected to increase twofold to MYR$66.62 millions, yielding 0.0029 per cent of GDP[7]. This 2030 percentage is relatively small compared to a developed country like Australia—the government expenditure on aged care in term of share to GDP is

[7] In 2012, Malaysian GDP was USD$314.442 billion or equivalent to MYR$943.326 billion. With 4.9% of GDP growth (average annual growth of GDP between 2006 to 2014), the expected GDP in 2030 is MYR$2, 232 billion. The Malaysian total health care expenditure as share a per GDP was recorded 4% in 2013. Source: `http://data.worldbank.org/country/malaysia`

estimated at 1.38 per cent in 2031 (Madge 2000). Thus, the amount of government spending on Malaysia public long term care costs is extremely low.

4.6.3 An economic evaluation of Malaysia public long term care

As the projected costs of Malaysian public long term care are expected to double by 2030, it is important to measure how effective these program are. Shiroiwa et al. (2013) suggested that costs per QALY is a good measurement for cost effectiveness in an economic evaluation. Therefore, we used the same measurement to examine the cost effectiveness of the Malaysian public residential care and nursing home programs. To perform this measure, we need the following data: long term care costs data, and the QALY of the elderly under each of the public long term care programs.

As for the first, the average annual costs per person for each Malaysian public institution were obtained in the previous section—MYR$14,504 for residential care and MYR$24,472 for nursing home care. Whereas for second, a QALY is measured based on an elderly's responses to the WHS (2002) questions that are related to the five dimensions of the EQ-5D—mobility (q2010), self-care (q2020), usual activities (q2060), pain or discomfort (q2030) and depression (q2090)—were collected, yielding the health state for each individual. Using the time-trade-off regression model from Yusof et al. (2012), the five digit code was reduced to a single index known as an *HRQoL* index. The *HRQoL* index is usually normalised to lie between 0 (death) and 1 (representing full health). Each of the elderlys' *HRQoL* indices are reported in Appendix 4.B.

The elderly who responded with a 3, or "major problem", in the mobility question are assumed to have some chronic condition, and are likely to need care in a nursing home. Whereas respondents with no, or minor, problems are assumed to be suitable for residential care. The average of respondents' *HRQoLs* allocated to each of these two groupings represents the mean score of the EQ-5D—the QALY for the groupings. In the calculations, shown in Appendix B, the QALY of those living in residential care and nursing home care were 0.632 and 0.423, respectively. The QALY of those living in nursing home care is, reasonably, lower than those in residential care due to their worse chronic health conditions with the majority being categorised as severely disabled. Nevertheless, it should

Table 4.22: Cost utility analysis of Malaysian public long term care programs. Cost values are in MYR$. Results show that nursing home care is not cost effective as costs per QALY fall outside the WTP per QALY threshold.

	Residential Care	**Nursing Home**
Average Costs	14,504	24,472
Average QALY	0.63	0.42
Costs/QALY	22,948	57,822
WTP/QALY	19,929–28,469	19,929–28,469
Effectiveness of the program	Effective	Not effective

be noted, due to data limitations, the QALY for the elderly requiring nursing home care—based on a small sample size (n=30). Thus, this QALY value may well not accurately represent the QALY for those living in nursing home. As this research is likely the first to study the effectiveness of Malaysian long term care, we will continue with this calculated value. However, we point out that future research is needed to conduct a rigorous EQ-5D survey of the elderly Malaysian living in public institutions.

The cost effectiveness of Malaysian public long term care is summarised in Table 4.22. The cost effectiveness of residential care program is MYR$22,948 per QALY, lower than the cost effectiveness of nursing home care—MYR$57,822 per QALY. These results reflect positively on the residential care program: it has the best (lowest) cost-effectiveness ratio, compared to nursing home care. It takes MYR$22,948 to generate an additional QALY in the residential care program; for nursing home care, the costs are MYR$57,822—more than double residential care costs.

For further analysis of the cost effectiveness of these programs the costs per QALY of each program were compared with Malaysians willingness to pay (WTP) for a quality adjusted life year (QALY). A study by Shafie et al. (2014) has estimated the WTP per QALY threshold for Malaysia lies between MYR$19,929 and MYR$28,469. In comparison to the WTP per QALY threshold, the costs per QALY of residential care program lies within the threshold, while the costs per QALY for nursing home care lies considerably above the cost effectiveness threshold. Hence, it would appear residential care is effective whereas the nursing home program is an ineffective option for Malaysian long term care.

Finally, we cast our net wider to compare the effectiveness of Malaysian public long term care programs with that of Japan. Results are summarised in Table 4.23 and for comparison purposes, all costs are converted to US dollars[4]. The average costs of long term care per person and the QALY values for Japan were obtained by an examination of the literature, as described below.

The average cost values for Japan were obtained from the study of Ihara (2011). The Japanese government provides full subsidies only for those who are below an income threshold. The Japanese social long term care insurance provides a level of benefits which varies among categories. The monthly benefit payment is about USD$2,300 per person (USD$27,600 per annum) for the most severe and about USD$500 dollars (USD$6,000 per annum) for the mildest. The estimated QALYs for elderly requiring low and high levels of care and the WTP threshold were obtained from Shiroiwa et al. (2013). This paper investigated the relationship between severity of health status and monetary value of a QALY. The study used 2,400 respondents from an online panel to obtain the Japanese willingness to pay for an additional QALY. The typical WTP per QALY threshold in Japan was viewed at the time as lying between USD$50,000 and USD$60,000. However Shiroiwa et al. (2013) argued that this threshold is not comprehensive and ignored the correlation between willingness to pay and disability status—severely disabled people do tend to pay more than less severely disabled people for an additional QALY. Hence, based on the survey, they develop a new WTP per QALY threshold in Japan which accounts for disability levels. This threshold ranges between USD$25,000 and USD$100,000 (Shiroiwa et al. 2013). The cost effectiveness of the Japanese public long term care insurance programs, together with Malaysian public long term care are summarised in Table 4.23

The results from Table 4.23 show that while Malaysian residential care is cost effective, as the cost per QALY value falls within the willingness to pay threshold, Japanese residential care is extremely effective as the costs per QALY value lies far below the minimum traditional WTP threshold. On the other hand, results show nursing home care in both countries are ineffective due to the costs per QALY values lie outside the traditional WTP range. One reason for this outcome is that the costs associated with nursing home care are far more expensive than residential care—double in Malaysia and more than quadruple in Japan. The high costs of nursing home care reflects the extensive care and medical attention needed to treat the severely disabled elderly. Shiroiwa et al.'s 2013 new version of the WTP per QALY threshold for Japan, in which the WTP per QALY is higher for worse health status than for better health status, included in Table 4.23 as 'Revised WTP/QALY'. Using the new threshold for Japan, nursing home care in Japan is now an effective long term care program; results for Malaysian nursing home care using such a metric are not available.

Further research is needed to developed both provide rigorous QALY values for Malaysian long term care programs and investigate the WTP per QALY threshold in this context.

Table 4.23: Comparative cost utility analysis between Malaysia and Japan's long term care programs. Nursing home care in Malaysia is not a cost effective program as the costs per QALY values fall outside the WTP thresholds. The long term care programs for Japan, low and high are both cost effective.

Country	**Malaysia**		**Japan**	
LTC programs	Residential Care	Nursing Home	Residential Care	Nursing Home
Average Costs	3,562	6,009	6,000	27,600
QALYs	0.63	0.42	0.77	0.34
Costs/QALY	5,654	14,286	7,792	81,176
WTP/QALY	(4,894–6,991)	(4,894–6,991)	(50,000–60,000)	(50,000–60,000)
Cost effectiveness	Effective	Not effective	Effective	Not effective
Revised WTP/QALY	(N/A)	(N/A)	(25,000–100,000)	(25,000–100,000)
Revised cost effectiveness	(N/A)	(N/A)	Effective	Effective

4.7 Conclusions

Population ageing is a topical issue in Malaysia. The proportion of older people has increased at rapid rate, resulting a greater demand for long term care. The sustainability of current long term care models in the country has been debated by researchers, together with suggestions for change and reform. Nonetheless, none provide quantifiable research about future demand and costs for Malaysian long term care. Therefore this paper seeks to contribute in this area of research.

The number of elderly Malaysian requiring long term care was projected up to 2040 using the multiple state method of Rickayzen & Walsh (2002). We extended an aspect of the methodology to include a different method for incorporating mortality improvement in projecting the number of elderly according to disability levels. The mortality improvement model that we used is the developed-developing countries coherence model which is based on Hyndman et al. (2013). Results indicated this method produced a slightly higher number of elderly in all disability categories for males and females compared to the reduction method used in Leung (2004) and Bueno (2013). This likely due to the developed-developing countries coherence model employing past time-series data to extrapolate future trends. In addition, using Australian mortality as the reference rate in the model, has resulted in Malaysian mortality improving better than that of the reduction factor method.

The number of elderly mildly and moderately disabled Malaysians have been projected to double from 2010 to 2030 for males and females, respectively. By 2040, the values are projected to triple for both genders from their 2010 levels. The increase for the severely disabled elderly is even more substantial than mildly and moderately disabled groups. By 2030 the severely disabled elderly will triple and by 2040 the amount will be quadrupled. These projected values indicated an increase in the demand for Malaysian public long term care. The number of people requiring residential care and nursing home care is expected to double the 2012 levels by 2030, when Malaysia is expected to become an aged nation. The total costs associated with the programs also double from MYR$32.59 millions in 2012 to MYR$66.62 millions in 2030—providing the existing policy remains the same throughout the projection years, i.e., the percentage entitled to public long term care remains constant.

An economic evaluation of each of the public long term care suggests that the residential care program is cost effective, while nursing home care for severely disabled people is not effective—but these latter results must be qualified. An international comparison of cost-effectiveness of long term care programs was made with Japan. Both low and high level residential care in Japan is cost effective, provided the WTP threshold accounts for the severity level of health states.

Worthwhile future research could address the better modelling of Malaysian disability trends. This, however, requires rich national disability data—currently not available. In addition, careful research to provide robust QALY values for Malaysian long term care programs, and the associated WTP per QALY threshold, would be valuable.

4.A Malaysia disability transition probabilities

MALE	Able	Mild	Moderate	Severe	Dead
Able					
18	0.98716	0.00948	0.00152	0.00056	0.00127
20	0.98653	0.00987	0.00159	0.00059	0.00142
30	0.98262	0.01262	0.00206	0.00077	0.00193
40	0.97538	0.01737	0.00291	0.00112	0.00322
50	0.96794	0.02037	0.00360	0.00146	0.00663
60	0.93387	0.03776	0.00734	0.00329	0.01774
70	0.87867	0.05643	0.01267	0.00656	0.04567
80	0.70922	0.08069	0.02149	0.01319	0.17540
90	0.65696	0.10944	0.03394	0.02427	0.17540
100	0.59735	0.14045	0.04838	0.03842	0.17540
Mild					
18	0.14915	0.84519	0.00320	0.00119	0.00127
20	0.14910	0.84490	0.00334	0.00124	0.00142
30	0.14882	0.84330	0.00432	0.00162	0.00193
40	0.14825	0.84006	0.00611	0.00236	0.00322
50	0.14742	0.83532	0.00755	0.00307	0.00663
60	0.14405	0.81590	0.01541	0.00690	0.01774
70	0.13737	0.77659	0.02660	0.01377	0.04567
80	0.11468	0.63709	0.04512	0.02771	0.17540
90	0.10857	0.59381	0.07126	0.05096	0.17540
100	0.10115	0.54119	0.10159	0.08068	0.17540
Moderate					
18	0.00000	0.14944	0.84680	0.00249	0.00127
20	0.00000	0.14940	0.84658	0.00260	0.00142
30	0.00000	0.14920	0.84546	0.00341	0.00193
40	0.00000	0.14878	0.84305	0.00495	0.00322
50	0.00000	0.14804	0.83887	0.00646	0.00663
60	0.00000	0.14520	0.82257	0.01449	0.01774
70	0.00000	0.13901	0.78641	0.02891	0.04567
80	0.00000	0.11649	0.64993	0.05818	0.17540
90	0.00000	0.11046	0.60715	0.10700	0.17540
100	0.00000	0.10273	0.55245	0.16942	0.17540
Severe					
18	0.00000	0.00000	0.12434	0.87037	0.00529
20	0.00000	0.00000	0.12422	0.86954	0.00624
30	0.00000	0.00000	0.12333	0.86328	0.01339
40	0.00000	0.00000	0.12154	0.85077	0.02769
50	0.00000	0.00000	0.11873	0.83113	0.05014
60	0.00000	0.00000	0.11501	0.80509	0.07989
70	0.00000	0.00000	0.10999	0.76990	0.12012
80	0.00000	0.00000	0.09300	0.65100	0.25600
90	0.00000	0.00000	0.09267	0.64868	0.25865
100	0.00000	0.00000	0.09254	0.64775	0.25972

(a)

FEMALE	Able	Mild	Moderate	Severe	Dead
Able					
18	0.98994	0.00781	0.00147	0.00037	0.00041
20	0.98908	0.00848	0.00160	0.00040	0.00044
30	0.98348	0.01283	0.00241	0.00061	0.00067
40	0.97900	0.01579	0.00297	0.00075	0.00148
50	0.96041	0.02881	0.00542	0.00137	0.00399
60	0.93460	0.04366	0.00822	0.00208	0.01144
70	0.88651	0.06346	0.01249	0.00330	0.03424
80	0.72964	0.07387	0.02676	0.01302	0.15671
90	0.68547	0.09241	0.04099	0.02442	0.15671
100	0.63279	0.12294	0.05477	0.03279	0.15671
Mild					
18	0.14890	0.84377	0.00553	0.00140	0.00041
20	0.14881	0.84324	0.00600	0.00152	0.00044
30	0.14820	0.83977	0.00907	0.00229	0.00067
40	0.14768	0.83685	0.01117	0.00282	0.00148
50	0.14559	0.82490	0.02037	0.00515	0.00399
60	0.14254	0.80730	0.03090	0.00781	0.01144
70	0.13627	0.77014	0.04694	0.01241	0.03424
80	0.10758	0.58617	0.10059	0.04895	0.15671
90	0.09539	0.50201	0.15408	0.09181	0.15671
100	0.08486	0.42928	0.20590	0.12325	0.15671
Moderate					
18	0.00000	0.14915	0.84519	0.00525	0.00041
20	0.00000	0.14908	0.84478	0.00570	0.00044
30	0.00000	0.14861	0.84211	0.00862	0.00067
40	0.00000	0.14819	0.83972	0.01061	0.00148
50	0.00000	0.14651	0.83014	0.01936	0.00399
60	0.00000	0.14393	0.81526	0.02938	0.01144
70	0.00000	0.13811	0.78101	0.04665	0.03424
80	0.00000	0.10322	0.55605	0.18402	0.15671
90	0.00000	0.08283	0.41531	0.34515	0.15671
100	0.00000	0.06789	0.31209	0.46331	0.15671
Severe					
18	0.00000	0.00000	0.12445	0.87112	0.00443
20	0.00000	0.00000	0.12434	0.87040	0.00526
30	0.00000	0.00000	0.12348	0.86438	0.01213
40	0.00000	0.00000	0.12176	0.85229	0.02595
50	0.00000	0.00000	0.11906	0.83344	0.04750
60	0.00000	0.00000	0.11580	0.81061	0.07359
70	0.00000	0.00000	0.11141	0.77990	0.10869
80	0.00000	0.00000	0.09534	0.66736	0.23731
90	0.00000	0.00000	0.09501	0.66504	0.23996
100	0.00000	0.00000	0.09487	0.66410	0.24103

(b)

4.B The estimation of QALY for elderly in public residential care and nursing home care

		Health States of Elderly in residential care (RSK)					
Health States (x)	n	MO	SC	PD	D	UA	TTO Score/U(x)
1	1	2	2	3	3	3	0.402
2	1	2	2	3	3	2	0.412
3	1	2	2	3	2	2	0.420
4	3	2	2	3	2	1	0.450
5	6	2	2	3	1	1	0.493
6	1	2	2	2	2	3	0.460
7	6	2	2	2	3	2	0.462
8	15	2	2	2	2	2	0.600
9	15	2	2	2	2	1	0.630
10	5	2	2	2	1	2	0.643
11	6	2	2	2	1	1	0.673
12	1	1	2	2	1	1	0.712
13	1	2	2	1	2	1	0.720
14	1	2	2	1	1	1	0.763
15	1	1	2	1	1	1	0.802
16	1	2	1	3	3	3	0.463
17	1	2	1	3	3	2	0.473
18	3	2	1	3	2	2	0.481
19	7	2	1	3	2	1	0.511
20	4	2	1	3	1	2	0.524
21	1	1	1	3	2	3	0.510
22	3	1	1	3	2	1	0.550
23	5	1	1	3	1	1	0.593
24	1	2	1	2	3	2	0.523
25	3	2	1	2	3	1	0.553
26	23	2	1	2	2	2	0.661
27	44	2	1	2	2	1	0.691
28	14	2	1	2	1	2	0.704
29	64	2	1	2	1	1	0.734
30	1	1	1	2	2	3	0.560
31	1	1	1	2	3	2	0.562
32	4	1	1	2	3	1	0.592
33	1	1	1	2	1	3	0.603
34	9	1	1	2	2	2	0.700
35	49	1	1	2	2	1	0.730
36	6	1	1	2	1	2	0.743
37	154	1	1	2	1	1	0.773
38	1	2	1	1	2	2	0.751
39	8	2	1	1	2	1	0.781
40	2	2	1	1	1	2	0.794
41	24	2	1	1	1	1	0.824
42	4	1	1	1	3	1	0.682
43	1	1	1	1	1	3	0.693
44	4	1	1	1	2	2	0.790
45	33	1	1	1	2	1	0.820
46	12	1	1	1	1	2	0.833
47	214	1	1	1	1	1	0.863
QALY	766						0.632

(c)

		Health States of Elderly in Nursing Home Care (RE)					
Health States (x)	n	MO	SC	PD	D	UA	TTO Score/U(x)
1	1	3	3	3	3	3	0.339
2	1	3	3	3	2	3	0.347
3	2	3	3	3	3	2	0.349
4	1	3	2	3	3	3	0.361
5	1	3	2	3	2	3	0.369
6	3	3	2	3	3	2	0.371
7	1	3	3	3	2	1	0.387
8	1	2	3	3	2	2	0.398
9	2	3	3	2	2	2	0.407
10	4	3	2	3	2	1	0.409
11	1	3	2	2	3	3	0.411
12	1	3	2	3	1	3	0.412
13	1	3	2	2	2	2	0.429
14	3	3	1	3	2	3	0.430
15	1	3	3	2	2	1	0.437
16	1	3	2	2	2	1	0.459
17	1	3	3	2	1	1	0.480
18	1	3	1	2	2	2	0.490
19	1	3	1	3	1	1	0.513
20	1	3	3	1	2	1	0.527
21	1	3	1	2	1	1	0.563
QALY	30						0.423

(d)

Chapter 5

Conclusion

As the Malaysian population ages, issues surrounding long term care, particularly concerning institutional or nursing home care, are coming more into focus (Dahlan et al. 2010). These issues have yet to be recognised in policy, which currently encourages children or family members to provide informal care giving to elderly parents. Although informal care has been long practiced by family members, this tradition is weakening over time due to a falling number of children, urbanisation and a higher percentage of labour force participation among women (Mafauzy 2000). Commentators suggest there is a degree of urgency for policy change or reform (Goh & Lai 2013, Ambigga 2011, Li & Khan 2012, Forsyth & Chia 2009). Nevertheless, little research has been done so far in estimating the expected change in the Malaysian population and the demand for long term care. Such information is crucial for the government to implement informed changes in long term care provisions.

This thesis fills the gap by providing comprehensive forecasts of the change in the Malaysian population and demand for long term care in the future. A variety of forecasting methods for Malaysian demographic components (mortality, fertility and net international migration) were carefully evaluated and chosen for this task. Demographic components were also stochastically forecast so that the uncertainty about the magnitude of change in each of the components could be estimated. Kudrna et al. (2013) suggested the estimation of the number of people requiring long term care should account for the uncertainty surrounding demographic change as well as the evolution of disability levels by age. Hence, in estimating the demand for public long term care services in Malaysia, the improvements in mortality, as well as disability, are accounted for. These investigations were divided into three separate papers. Each of the papers are summarised below, together with their main findings.

5.1 Summary and findings

5.1.1 Paper 1

The first study investigated various mortality projections, including two recently published coherent models—Poisson Lee & Carter (Li 2013) and product-ratio (Hyndman et al. 2013)—and their independent versions—Poisson Lee & Carter (Brouhns et al. 2002) and functional independent (Hyndman & Ullah 2007)—as well as the original Lee & Carter (1992) model.

The out-of-sample forecast errors of age-specific death rates, male to female death rate ratios and life expectancy at birth of the different methods were estimated and compared to each other. As far as we are aware, the comparison of the forecast accuracy between the two new coherent models has not been documented in the literature before. This paper fills the gap by comparing the coherent models as well as the coherent models and independent models. The application of coherent models is extended to account for two types of coherency, gender as well as ethnicity. For gender coherence, for example, Malay males were jointly forecast with Malay females, whereas ethnic coherence jointly forecast Malay males together with Chinese males and Indian males.

While coherent models outperformed independent models for both Australian males and females, coherent models performed less well than independent models for Malaysian males—which, at the same time, performed well for Malaysian females. Further investigation found that coherent models outperformed independent models for Malaysian males when using a longer fitting period—by extending the fitting period, the constant linear decreasing pattern of male mortality that occurred in more recent years can be captured.

Among the coherent models this study found that the product ratio models produced slightly better forecasts than the Poisson common factor model for Australian males and females and Malaysian females. These models, however, performed less accurately for Malaysian males. The product ratio method uses the weighted functional technique that applies geometrically decaying weight procedures—giving a greater weight to more recent, rather than earlier, data.

This weighting seems not suited for Malaysian males because observed Malaysian male mortality in the forecast period is inconsistent with the most recent trend in the fitting period due to recent structural change in male mortality. Thus, applying greater weight to the most current trend leads to poor estimation of the forecast trend. Again, if a similar extended fitting period was applied to Malaysian male mortality, it turned out that the product ratio model outperformed the Poisson common factor model.

The application of coherent models to Malaysian sub-populations by ethnic groups suggested the ethnic coherence models are more accurate than both gender coherence and independent models for four out of the six sub-populations. This suggests that the incorporation of lower mortality of the same gendered sub-population in the coherent model is more accurate than lower mortality of the opposite gendered sub-population.

5.1.2 Paper 2

Growing concern about the uncertainty surrounding population forecasts motivated this research—to provide long term stochastic population projection for Malaysia as opposed to the existing official projections by the *DoSM*, which are based on deterministic scenarios.

Paper 2 adopts the coherent stochastic population forecasting model of Hyndman (2014) and Hyndman & Booth (2008) to forecast the age-specific Malaysian population by gender and ethnic groups. This method provides a flexible framework for population projections which allows each population component (mortality, fertility and net international migration) to be modelled and forecast using the same methodology. The forecast values of each component are then combined using the cohort component method to obtain age-specific population forecasts. Coherent models have been shown to produce more accurate out-of-sample forecasts than the independent models and the Lee & Carter model (Hyndman et al. 2013, Shair et al. 2015). Thus, the coherent stochastic population forecasting model from Hyndman (2014) was adopted and extended to treat Malaysia mortality rates, as well as fertility rates and net international migration.

This approach requires age-specific time series data for each component. While such data are available for mortality and fertility, net international migration data for Malaysia have never been published. This paper fills the gap by estimating age-specific Malaysian net international migration over the observation period from 1970 to 2009 using the growth-balance method. Moreover, following Li & Lee's (2005) suggestion, in addition to gender coherence, we explored the possibility of jointly forecasting Malaysian demographic rates with Australian rates using the proposed type of coherency known as developed-developing countries coherence. Paper 1 suggested the association of lower mortality of the same gendered sub-population in the coherent model provided more accuracy in out-of-sample forecasts than the lower mortality of the opposite gendered sub-population. Hence, this paper jointly forecasts the vital rates of Malaysian males with Australian males and Malaysian females with Australian females.

The out-of-sample forecasts of the population component are evaluated and compared between various models: the independent model, gender coherence model and developed-developing countries coherence model. The main findings suggested the developed-developing countries coherence model worked well in forecasting Malaysian male and female demographic components. The model outperformed the independent and gender-coherence for both genders. Nevertheless, careful attention must be paid as to how the mortality or fertility trends of both countries changed over times. We found that differences in mortality structural changes between the two countries may lead to higher forecast errors. The developed-developing countries coherence population models also worked well for three out of six Malaysian ethnic sub-populations: Chinese males, Chinese females and Malay females. In comparing each projection with that of the *DoSM* under its medium variant, our mean coherent forecasts are expected to age at a more rapid pace due to sustained low fertility and increasing life expectancy assumptions. In coherent forecasts, elderly Malaysian males will reach 15% of total population (aged status) by 2034, five years before than that of the *DoSM* medium variant forecast.

5.1.3 Paper 3

In Paper 3 we projected the number of elderly Malaysians who are disabled and require long term care—up to 2040. The transition probabilities of lives becoming disabled and the extent to which they are disabled were estimated using the multiple state model from Rickayzen & Walsh (2002).

The transition probability from one disabled state to a more or less severely disabled state is best estimated using longitudinal data in which the change in health status of each respondent can be monitored over one or more years. Such data are limited in Malaysia, typically covering only a smaller area of the nation[1]. Alternatively, comprehensive longitudinal survey data from other countries can be adopted, but these data may not represent the real disability experience of Malaysians (Hariyanto et al. 2013). In order to avoid the use of longitudinal data, Rickayzen & Walsh (2002) have developed a model that requires single year cross-sectional disability prevalence rates. Such data are commonly available from national statistical or health departments. Unfortunately, cross sectional disability data for Malaysia are scarce. The Malaysian disability prevalence rates can be obtained from the National Health Morbidity Survey, however data according to disability levels (for example, mild, moderate and severe) are not available. We resort, instead, to WHS (2002) data which yield estimates of Malaysian disability prevalence rates segregated by age, gender and disability categories.

The Rickayzen & Walsh (2002) model has been applied in several countries, including Australia (Leung 2004, Hariyanto et al. 2013) and Brazil (Bueno 2013). We adapt the model to Malaysia, however, we extend the projection component of the model to include another type of mortality improvement. In addition to the Continuous Mortality Investigation Bureau (1999) method, we also included a method that could predict the improvement in mortality using past time series data—developed-developing countries coherence. This method proved successful in Paper 2 in application to Malaysian mortality and population forecasts.

The projected elderly Malaysian population according to disability levels is useful to estimate the likely number of the population requiring public institutional long term care programs—residential care and nursing home care. The total expected costs for the public long term care programs are estimated based on the disabled population projections. In addition, we include a cost utility analysis for each program in term of costs per QALY. This measurement is important to determine whether the current public long term care programs provided by government are cost effective or otherwise. The cost effectiveness of the public long term care programs were compared to those of a more developed country, Japan.

The findings of Paper 3 suggested that multiple state model's prevalence rates replicated the Malaysian prevalence rates quite well, indicating that the parame-

[1] See, for example, Chen et al. (1983).

ters of the probability of deterioration had been estimated sensibly. The effect of using different mortality improvement assumptions on projection methods showed that the method that accounts for coherency between developed-developing countries consistently produced a higher projected number of people in each category compared to the Continuous Mortality Investigation Bureau (1999) method. Results show that the projected number of disabled elderly Malaysians are expected to increase substantially for each of the disability categories in the future. By 2030, the mildly and moderately disabled elderly will increase to more than double the 2010 observations, whereas the severely disabled elderly will increase to more than three times the 2010 values. The increase in the disabled elderly population will result in the expected demand for public residential care and nursing home care to double by 2030, given that the current percentage of entitlements for the programs remains the same throughout the projection years. Accordingly, the total costs of public long term care is expected to grow from MYR$32.59 million to MYR$66.62 million in 2030 and to MYR$83.20 million in 2040.

In addition, the cost utility analysis results showed that residential care programs provided by the government appear cost effective as the costs per QALY value for this program fall within the Malaysian willingness to pay threshold. On the other hand, the nursing home care program seems not cost effective—but these results must be qualified as they are based on a small sample.

5.2 Recommendations for future research

Paper 1's findings suggest coherent models have the potential to be more accurate than independent models for Malaysia, provided the right fitting period and type of coherency are chosen. Other types of coherency, such as urban and rural coherence should also be considered.

In Paper 2, although the out-of-sample forecast evaluation indicated that the developed-developing countries coherence population model outperformed other methods, it is impossible to say that the same model will be more accurate than that of the *DoSM* for such long term population forecasts. Future work monitoring the performance of these long term coherent population forecasts against those of the *DoSM* would be useful. Furthermore, we leave the possibility of using other countries, preferably low mortality and fertility countries, to determine the best reference rates for Malaysian sub-populations to future work. In a similar vein, another task is to explore for which countries Malaysian demography could serve as a worthwhile reference in such coherent forecasting.

In Paper 3 an alternative method for mortality improvement based on observed Malaysian time series data was proposed in the context of the Rickayzen & Walsh (2002) model. This method, however, cannot be applied to disability due to the limited availability of Malaysian disability prevalence rates. For this paper, the improvement in disability was based on pre-determined assumptions that the rates will be exponentially decreasing at a certain percentage. Should richer national disability data become available, it would be interesting to develop a method that could estimate disability improvement based on Malaysian past experience. Further, the paper calculated the QALYs of disabled elderly Malaysian in public long term care programs using a proxy EQ-5D survey, which generated only qualified results. Another possible extension to Paper 3, where it could include an EQ-5D survey for elderly Malaysian living in public residential care and nursing home care. Also of the same interest would be to work on the WTP per QALY threshold for Malaysia suitable for use with long term care or disability policy.

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