Max-Planck-Institut für demografische Forschung
Max Planck Institute for Demographic Research
Konrad-Zuse-Strasse 1 · D-18057 Rostock · GERMANY
Tel +49 (0) 3 81 20 81 - 0; Fax +49 (0) 3 81 20 81 - 202;
http://www.demogr.mpg.de

MPIDR WORKING PAPER WP 2007-032
OCTOBER 2007

Aging of a giant: a stochastic population forecast for China, 2001-2050

Qiang Li (li@demogr.mpg.de)
Mieke Reuser (reuser@nidi.nl)
Cornelia Kraus (kraus@demogr.mpg.de)
Juha Alho (etunimi.sukunimi@ joensuu.fi)

This working paper has been approved for release by: Jutta Gampe (gampe@demogr.mpg.de)
Head of the Office of Statistics and Information Services.

AGING OF A GIANT: A STOCHASTIC POPULATION FORECAST FOR CHINA, 2001-2050

Dr. Qiang Li, † Max Planck Institute for Demographic Research

Ph.D student **Mieke Reuser**, Netherlands Interdisciplinary Demographic Institute

Dr. **Cornelia Kraus**, Max Planck Institute for Demographic Research

Prof. Dr. **Juha Alho**, University of Joensuu

Affiliations:

† Address for correspondence: **Qiang Li**, Max Planck Institute for Demographic Research, D-18057 Rostock, Germany. Email: li@demogr.mpg.de.

Mieke Reuser

Netherlands Interdisciplinary Demographic Institute (NIDI), 2505 AR, The Hague.

Email: Reuser@nidi.nl

Cornelia Kraus

Max Planck Institute for Demographic Research, D-18057 Rostock, Germany. Email: kraus@demogr.mpg.de

Juha Alho

University of Joensuu, Department of Computer Science and Statistics, Box 111, 80101 Joensuu, Finland. Email: etunimi.sukunimi@ joensuu.fi

Abstract

This paper presents a stochastic population forecast for China with a special emphasis on population aging. Stochastic forecasting methods have the advantage of producing a projection of the future population including a probabilistic prediction interval. The so-called scaled model for error was used to quantify the uncertainty attached to the population predictions in this study. Data scarcity was a major problem in the specification of the expected error of the population forecast. Therefore, the error structures estimated for European countries were employed with some modifications taking the large size and heterogeneity of the Chinese population into account. The stochastic forecast confirms the expectation of extremely rapid population aging during the first half of the 21st century in China. The old age dependency ratio (OADR) will increase with certainty. By mid-century, with 80% probability, the OADR will lie between 0.41 and 0.56, with the median of the predictive distribution being 0.48, nearly five-fold its current value of 0.1. In particular, the oldest-old population will grow faster than any other age group. This development has major implications for China: to smoothly adjust current birth control policies to less restrictive ones, strengthen the family support system, and improve the social security system for the elderly.

Keywords: stochastic population forecast, predictive distribution, uncertainty, scaled model for error, China, population aging

Introduction

China, with more than one-fifth of the world's inhabitants, represents a significant factor in the development of the world's population. As a result of a dramatically declining fertility and a steadily increasing life expectancy, China's population is currently aging at a rapid rate. In 1982, the proportion of the elderly (65 and older) [1] was 4.91% of the total population, and this share increased to 5.57% and 6.81% in 1990 and 2000, respectively. In China it may take only about 20 years for the elderly population to increase from five to seven percent, while in many developed countries it usually takes about 50 to 80 years to develop the same level of population aging (Li 2005). Hence, population aging is likely to be one of the great challenges China will face in the near future.

As in most countries, the phenomenon of population aging in China results from the combined forces of mortality improvement and declining fertility, the latter process being especially pronounced due to Chinese birth control policies. In February 2006, the Chinese government announced the continuation of its birth planning policies. Starting with the restrictive one-child policy in 1980, these policies have moved to a one-child policy in urban areas[2] and a 1.5-child policy in rural areas (e.g., if the first child is a girl, the couple is allowed to have a second child, Zeng and George 2000). These policies, prescribing a below-replacement level of fertility by law, have a large effect on recent and future fertility, leading to an acceleration of population aging. The effects of these policies will also reduce family size, and consequently influence family support for older adults, such as instrumental and financial support, as well as care-giving and emotional support -- factors playing a major role in taking care of the elderly in China (Zimmer and Kwong 2003).

Mortality in China has declined steeply over the past 50 years, especially in the early years of the People's Republic of China (Banister and Hill 2004; Riley 2004). Life expectancy has increased from 48 years in 1950-1954 to over 71 years by 2000 (Banister and Hill 2004). Much of the mortality decline can be attributed to the decline in infant and childhood mortality rates achieved by an overall increase in the standard of living and the educational level of the Chinese population (Banister and Hill 2004; Riley 2004). With further improvement of socio-economic development, this mortality decline is likely to continue in the near future.

The Chinese social security system for the elderly is currently being transformed from a solely government-financed system to a government-subsided one. There are limited numbers of older people who receive a pension (Zhang and Xiao 1999). For example, in 1987, 63.7% of the elderly living in urban areas received pensions, and 56.63% and 4.7% in small towns and the countryside, respectively (Zhang and Xiao 1999). The coverage of medical care cost is about 50% for employees in the cities and less than 10% for rural inhabitants (Woo et al. 2002). Most of the older people in China are poor and cannot support themselves. Furthermore, with family size declining, the younger generation will not be able to offer the traditional family care, even if they are willing to do so (Li 2005). Therefore, projecting the Chinese population into the near future is of high importance also for providing the relevant demographic background for appropriate socio-economic policy decisions.

Forecasting the Chinese population is a challenging task. Firstly, China has been experiencing major demographic changes in the recent past. The implementation of birth control policies starting in 1970, especially the introduction of the one-child policy in 1980, has resulted in a rapid fertility decline. The high rate of economic growth since the Reform and Open-up policy in 1978 has improved public health and living conditions, whereas the collapse of the healthcare system has negatively impacted the population's health status, and both have jointly affected the average life expectancy. Secondly, data available for forecasting are very scarce. Census data for only four time points are available for forecasting mortality. Somewhat more data on fertility are available, but data quality is not too high. For example, fertility rates have been underestimated in several surveys and even in census data. Moreover, estimates for total fertility rate (TFR) based on different data sources are not consistent with each other. Stochastic approaches to forecasting cope with these kinds of uncertainty by assuming a probability distribution for the projected parameters. Several methods for stochastic forecasting have been proposed previously (e.g., Lee and Carter 1992; Alho and Spencer 2005). In this study the so-called scaled model for error is employed, which has been developed by Alho and Spencer (2005: 280-283) and which has been extensively applied to the projection of European populations (e.g., Alho and Nikander 2004; Alho et al. 2006).

To date, most population forecasts for China have used deterministic projections, which assess the range of possible outcomes by high and low scenarios. Deterministic models have some drawbacks, however. It is not clear how to interpret a population variable’s high -- low range unless a corresponding probability for the range is provided (Li, Lee and Tuljapukar 2004). In addition, alternative scenarios based on judgment have tended to under-predict mortality declines and gains in life expectancy when compared with the subsequent outcomes (Keilman 1997, 2001; Lee and Miller 2001). These errors have led to under-prediction of the elderly population, and particularly the oldest-old (Li, Lee and Tuljapukar 2004), which could impede population aging research. To our knowledge, there are only two stochastic forecasts for China: one is a mortality forecast by Li, Lee and Tuljapukar (2004); the other, by Lutz et al. (2005), is a population forecast based on expert opinion rather than empirical analysis. However, neither of these two studies provides a detailed analysis of population aging.

This study reports the results of a stochastic forecast of the Chinese population between 2001 and 2050. The forecasting approach follows Alho and Spencer (2005). Focusing on population aging, the main aims are to (i) provide probabilistic predictions of total population size and (ii) to quantify the level and rate of the population aging process using various indicators of age structure. The paper is organized as follows: Section 2 introduces the data sources and forecasting methods and assumptions for population processes. Stochastic forecasting results are provided in Section 3. Section 4 concludes the study by summarizing the main forecasting results on population aging and briefly discusses their policy implications.

Materials and methods

Data sources

The sources of data used in this projection are detailed in Table 1. Jump-off population data are based on the 2000 census. Fertility data mainly come from the 2000 census and the surveys conducted by State Family Planning Commission of China (SFPC) in 1982, 1988, 1992, 1997 and 2001. Some additional fertility data are provided by the National Bureau of Statistics of China (NBS). Mortality data are from three censuses undertaken by NBS in 1982, 1990 and 2000, as well as the Cancer Epidemiology Survey carried out by the Ministry of Health in the 1970s.

---- Table 1 is here -----

Forecasting method

Stochastic population forecasts are calculated by using cohort-component bookkeeping under a linear (Leslie) growth model, with a deterministic jump-off population and probabilistically varying values for age-specific fertility, age-sex-specific mortality, and net migration flows by sex and age. The *scaled model for error* was applied to specify uncertainty (Alho and Spencer 2005: 280-283). It assumes that the demographic rate for age *j* at forecast year *t* (*t*>*0*) can be expressed as follows:

$$R(j,t) = F(j,t)\exp(X(j,t)),$$

where *F(j,t)* is the point forecast and *X(j,t)* is the error process which is modeled by a random walk with a drift (in *t*). The error process is of the form $X(j,t) = \varepsilon(j,1) + ... + \varepsilon(j,t)$, where the error increments are given by

$$\varepsilon(j,t) = S(j,t)(\eta_j + \delta(j,t)).$$

Here, *S(j,t)* is always positive and can be seen as a weight or scale on the error term $\varepsilon(j,t)$. If an appropriate *S(j,t)* is chosen, a random walk with a drift will replicate the errors in the future well. η_j represents the error in the forecasted trends, and $\delta(j,t)$ describes the random fluctuations around these trends. It is assumed that for each *j*, the variables $\delta(j,t)$ are independent over time. Additionally, the variables $\delta(j,t)$ are assumed independent of the variables η_j with both following a normal distribution:

$$\eta(j) \sim N(0,k_j)\,;\ \delta(j,t) \sim N(0,1-k_j),$$

where $0 < k_j < 1$ are known. In addition, autoregressive (AR(1)) correlation structures on η_j and $\delta(j,t)$ across age (fertility and mortality) and sex (mortality and net migration) are assumed:

$$Corr(\eta(i),\eta(j)) = Corr(\delta(i,t),\delta(j,t)) = \rho^{|i-j|} \text{ for some } 0 \le \rho \le 1.$$

Since the increments are scaled by the *S(j,t)*, the model is called the scaled model for error. The function of the correlation parameters in terms of age is to represent the phenomenon that forecast errors of vital rates in close ages tend to be similar, but in distant ages they may be quite different.

Note that $k_j = Corr(\varepsilon(j,t), \varepsilon(j,t+h))$ for all $h \neq 0$. Therefore, the k_j indicates the independence or dependence of time and is always between 0 and 1. Under a random walk model, the error increments would be uncorrelated, with $k_j=0$. Empirical studies on European countries have shown that this may be appropriate in fertility forecasting (Alho and Spencer 2005: 254-255). When $0 < k_j < 1$, a random walk with a drift is defined. Again, empirical data from Europe suggest a random walk with a drift in the case of mortality and net migration forecasting (Alho and Spencer 2005: 255-256).

Alho and Spencer (2005: Ch. 8) distinguish three different methods to determine the predictive distribution for the vital rates: (1) extrapolation of time-series data, (2) expert opinion and (3) assessment of accuracy of past forecasts. However, in order to apply time-series extrapolation methods, long and accurate data series from the past are necessary, which are not available in the case of China. Thus, point estimates for fertility, mortality, and migration were based on the scarce information available and expert opinion (see Section "Assumptions for population processes"). The data available for China are too scarce to estimate country-specific levels of uncertainty based on the so-called "naive" or baseline forecasts which estimate the forecast error as the median level of uncertainty in the past. Therefore, this study borrows the forecasting error structure estimated by Alho and Spencer (2005) applying the scaled model for error to some European countries. With regard to China's huge population, however, some downward adjustments of the European values of scale $S(j,t)$ were made. This seems appropriate because past forecasts of China have been more accurate than those of European countries (Bongaarts and Bulatao 2000).

A general empirical finding is that forecasts of large countries have tended to be more accurate than those of smaller countries (Alho and Spencer 2005: 261). Intuitively, the better accuracy appears to be due to the fact that large countries often consist of somewhat independent sub-populations. Thus, the aggregate behaves in a more stable manner than the parts. Borgy and Alho (2007) used a similar approach to forecast the population for regions lacking demographic data of sufficient quality. In this study, the three scales of fertility, mortality and international migration were multiplied by three constants, whereas in the Borgy and Alho study all uncertainty parameters were multiplied by one constant only.

For fertility, mortality and migration, it was assumed that the uncertainty increases with the time forecasted and that the variances of the demographic processes are independent of each other. The errors for fertility are assumed to follow a random walk with $k_j=0$, while for mortality the autocorrelation of errors is presumed to increase, thus specifying a random walk with a drift, with k_j=0.05. The uncertainty of migration is expressed in absolute numbers and is again modeled by a random walk with a drift, with k_j=0.3. The specification details of uncertainty parameters for the three vital events will be discussed shortly.

The forecast was made using the BEGIN (Yanulevskaya and Alho 2005) and PEP (Program for Error Propagation, Alho and Mustonen 2003) programs, which are based on the scaled model for error. BEGIN creates the forecasting error parameters and produces output data files that serve as input in a subsequent PEP run. The cohort component model was run 3000 times in PEP to determine the probability distribution of future population size and structure. Forecasting results are reported as median with the accompanying 80% prediction interval, because in most cases 80% intervals give a better impression of forecast uncertainty than the more usual 95% intervals, which reflect extremes (Alders, Keilman, and Cruijsen 2007).

Assumptions for population processes

Jump-off population

The latest time point for which detailed population data for China is available is the census of 2000 conducted by the Chinese NBS. It provides information on the population by age (up to 100+) and sex. The reference time for the census is 00:00, November 1, 2000. Total population was 1,265 million in 2000. The 2000 population census was conducted on a *de jure* basis. The *de jure* count included all persons who hold the nationality of, and have their permanent place of residence[3] in the People's Republic of China. During the census, each person was enumerated in his/her permanent place of residence and should have been enumerated in one place only (Population Census Office 2002).

With regards to the quality of the jump-off population data, the post-enumeration sample survey indicated an undercount of 1.81% in the census enumeration (Population Census Office, 2002). Thus, it was necessary to adjust the age-sex-distribution of the jump-off population before forecasting. Based on the population census data in 1982 and 1990, as well as annual population size from 1981 to 2000 reported by NBS in 2002, Wang Guangzhou (2004) used survival analysis and target analysis to analyze, evaluate and adjust the age-sex structure data in the 2000 census. The total population size from Wang's estimation was 1.261 billion – close to the 1.265 billion reported by NBS.

To obtain a jump-off population starting at the turn of the year, Wang's adjusted population estimate was projected forward to 31 December 2000 under the assumption that mortality and fertility in the last two months were constant across months. This procedure resulted in a jump-off population of 1.260 billion at the end of the year.[4] Given the quality of the jump-off population data, additional errors could have been considered in this forecast model. Unfortunately, the current version of PEP does not allow including this kind of uncertainty.

Fertility

The latest source of information on age-specific fertility in China comes from the 2000 census. The TFR according to the census was 1.23. However, undercounts were estimated at 25% in the post-enumeration sample survey, suggesting that the real TFR had been 1.62 in 2000 (Retherford et al. 2005; Guo 2006; Zeng 2006). The age-specific fertility rates (ASFR) were adjusted accordingly. The lowest age for which fertility rates are available is 15 years and the highest age is 49 years. The ASFR for 2000 are abridged in 5-year age groups. The coefficients of the Karup-King formula were used to break these groups down to single-year fertility rates (Shryock 1976).[5]

Fertility assumptions for China in the forecast were based on the past trends in fertility in 1950-2000 and birth control policies. The latter have played a crucial role on fertility decline and population control in China, and will also affect future fertility levels. Before 1970, TFR fluctuated strongly. The dramatic decline at the end of the 1950s and the beginning of the 1960s were due to the Great Leap Forward beginning in 1957, and subsequently the catastrophic famine of 1959-1962. After that, the TFR increased to a higher level than before the Great Leap Forward and the famine (Figure 1: TFR, 1950-2000). In the past three decades, the fertility trend in China has been dominated by the impact of the "delayed childbirth (wan), longer birth intervals (xi), and fewer births (shao)" policy of the 1970s, the famous one-child policy introduced in 1980, and the current policy of allowing one-child in urban areas and 1.5-child in rural areas (from 1984 onwards, couples are allowed to have a second child if the first child is a girl). As a result of these policies, the fertility declined dramatically from 5.79 to 2.75 in the 1970s, fluctuated between a maximum value of 2.86 and a minimum of 2.19 during the 1980s, and then fell substantially in the 1990s. Despite differences in TFR estimated from different data sources, the declining trend in fertility during the 1990s is evident (Figure 1: TFR, 1950-2000).

---- Figure 1 is here -----

According to the current birth control policies, the TFR target is 1.47 (Guo 2004; Gu et al. 2007).[6] Since China announced in February 2006 it would continue these policies,[7] the downward trend is expected to continue until the target TFR 1.47 is achieved in the near future. The year in which the target TFR will be/has been reached was estimated based on the trend of the past TFR. Since the data from the sampling surveys undertaken by SFPC in the 1990s turned out to be severely biased on the low side (a regression suggested that the target TFR had been already reached in 1995), the estimation simply extrapolated the linear trend determined by two well-supported data points, namely 1985 and 2000 (undercount corrected census data). The 1985 survey data was used instead of the 1982 census data because the TFR in 1982 was exceptionally high. Thus, the steepness of the fertility decline would likely have been overestimated, which would have led to an unrealistically early reaching of the target TFR. The high TFR of 1982 is likely a period effect due to a short-term reaction of the Chinese population to the one-child policy and the 1980 Marriage Law (Griffith et al. 1989). The 1980 Marriage Law resulted in many more marriages in the early 1980s than in the 1970s; many marriages were postponed from the 1970s to the beginning of the 1980s, and subsequently led to a peak in childbirths. The scenario we have described suggests that the target TFR had been reached in 2004 (Figure 1), which is close to Guo's (2004) simulation where the target TFR would be reached in 2005.

In the point forecast of TFR it was assumed that the target TFR of 1.47 could be kept constant in the future, i.e., until 2050. This assumption is based on the following considerations. There is no sign at the moment that China will loosen its birth control policies, for example, allowing every couple to have two children. Moreover, previous studies have reported a declining trend in the Chinese fertility ideal, from 3 in the 1970s to 1.66 in 2002 (Chen and Zhang 2002; Parish and Whyte 1978; Wang 1996). Furthermore, young generations have accepted and internalized the policy into their culture in many places, especially in big cities such as Shanghai, Beijing, Dalian and Shenyang (Nie and Wyman 2005). Particularly, young Chinese women today are more likely to consider childbearing not as a necessity, but as a choice. This may also be due to the rising competition in the labor market as well as the costs of having more than one child.

The scaled model for error was used to specify the uncertainty of the fertility assumption. Given the very limited data available for China, this study borrowed the basic error structure provided by programs BEGIN and PEP. The default values in BEGIN and PEP were estimated by Alho and Spencer (2005: 253-255) using six European countries (Denmark, Finland, Iceland, the Netherlands, Norway and Sweden) over the time span starting between 1751 and 1900, and ending in 2000. This period includes much turbulence in fertility patterns in the countries studied, e.g., the "baby boom" and the rapid fertility declines at the end of the baby boom. Thus, the error structures derived can also serve as a plausible starting point for other countries and areas, such as China. It seems reasonable to assume that uncertainty patterns in China's fertility resemble the European error structures to some extent.

The current birth control policies are actually localized, that is, local governments have modified the state policy of population control in their prefectures according to their own situation, under the general principle of slowing down population growth and encouraging only one child per couple (Gu et al. 2007). As a result, different policies are applied within the total population, i.e., 35.4% of the population fell under the one-child policy and 53.6% the 1.5-children policy at the end of 1990s (Gu et al. 2007). The target TFR of 1.47 was estimated based on local fertility policies and corresponding population distribution (Gu et al. 2007). Borders and classification (urban versus rural) of China's prefectures are changing frequently, and accordingly, the number of people subject to different policies is also changing. This will likely result in some turbulence in the TFR during the forecasting period. In addition, there is still some possibility to see even a reversal of the declining trend in TFR in parts of country, especially in the poor rural areas where son preferences dominate and the government's control is comparatively weak (Kahn 2007).

The default values of the fertility scales in BEGIN and PEP, however, are slightly modified downwards, taking into account the large size of the Chinese population compared to the European countries the default values are based on. The modification is mainly built on the following empirical evidence. Bongaarts and Bulatao (2000: 210, 339) estimated the relative error for the total population of China in 2050 at the lead time of 50 years, using composite bootstrap procedures. Based on the European data, Alho and Spencer (2005) showed that after a lead time of about 50 years the levels of forecast error are similar for fertility and mortality, thus, they were constrained to be equal at the end of the forecasting period. In this study, the scales for fertility, mortality and net migration were adjusted until the relative error for the total population in 2050 matched the estimate by Bongaarts and Bulatao (2000). This process resulted in a relative error for fertility of 0.32 in 2050.

In Figure 2 the predictive distribution of TFR is compared to the point forecast of TFR underlying the median scenario of the UN projection. The UN forecast is much higher; it assumes the TFR to converge toward a level of 1.85 in 2015 and is held constant at that level for the remainder of the projection period (i.e., until 2050). The 80% prediction interval in this study covers the UN median forecast from 2028, and the 95% prediction interval covers that from 2017 onwards. It should be noted that the current fertility assumptions differ considerably from those of the UN. However, assumptions used in this study seem plausible, given the magnitude of fertility changes during the past 30 years of birth control policies, and the confirmed continuation of these policies in the near future, as well as the change of the fertility ideal and fertility desire of the younger generations. These assumptions lead to 80% prediction intervals of [1.18, 1.83] in 2025 and [1.07, 2.01] in 2050, and 95% prediction intervals of [1.11, 1.95] and [0.98, 2.20], respectively.

----- Figure 2 is here ----

In addition, assumptions for two additional variables, the mean age of childbearing (MAC) and sex ratio at birth (SRB) are required for the forecast. During the 1990s, while the TFR declined, the MAC remained stable. In 2000, the fertility rate for parity 3 reached a very low level, and a substantial further decline therefore seems unlikely (Guo 2004). Thus, it was assumed that the MAC, without consideration of parity, will remain constant at 26.00 years until 2050. The SRB in China has begun to increase above the average (1.05) since the 1980s and has kept rising steeply, reaching 1.17 in 2000. A high incidence of prenatal sex determination and sex-selective abortion are the main causes of the high SRB (Hesketh and Xing 2006). This has caused a female deficit in the ages 0-19 of 19.81 million in 2000 (Yuan and Tu 2005). Here, the point forecast of the SRB is expected to remain constant at 1.17, since there is currently no evidence for an increasing or decreasing trend in SRB in China.

Mortality

Age-specific mortality data for China are only available for the years 1973-1975, 1981, 1990 and 2000. Data for the years 1981, 1990 and 2000 come from the census of 1982, 1990 and 2000. The 1973-1975 data stem from the nationwide mortality survey, the "Cancer Epidemiology Survey" that attempted to record all deaths in nearly all of China's counties and city districts for the 3-year period 1973-75. This survey provides age-sex-cause-specific mortality rates for the period 1973-75. In China, the years 1973-75 represented the time when both rural and urban populations were covered by basic but efficient health-care systems (Banister and Hill 2004; Li, Lee and Tuljapukar 2004). By 1981, the rural health-care system had collapsed, and the city health-care system became inadequate due to the Reform and Open Up policy launched in 1978.

Mortality rates are given for single age-classes, but only up to age-class 90+. Thus, it was necessary to extrapolate mortality trajectories for the ages 90 to 100+. The Kannisto model (Thatcher, Kannisto, and Vaupel 1998; Zeng and Vaupel 2003) was used to extrapolate death rates up to age 100+.[8] As was the case for fertility data, the latest source of information on life tables comes from the 2000 census in China.

Due to data limitations, mortality assumptions in the forecast were not only based on the observation of past trends in China, but also borrowed from other countries. The age-specific rates of initial decline and ultimate decline in mortality are needed for the forecast. The former was estimated using the available Chinese data, whereas the latter was borrowed from the European countries.

Since its establishment, the People's Republic of China has experienced a rapid decline in mortality. Life expectancy has increased from 48 years to over 71 years during the past 50 years, around 0.46 year per year (Banister and Hill 2004). In the past three decades, for both sexes, an improvement of mortality at most ages has been observed, except for ages 20-23 between 1973-75 and 1981 (Figure 3). The decline of mortality for men has been more modest than for women, especially in adulthood (Figure 3). One possible explanation is that the improvement of mortality for men has been slowed down by sex-biased occupational and lifestyle factors, such as smoking and alcohol consumption, while women have benefited from a steep decline in fertility, concentration of childbearing at the healthiest ages, longer spacing between births, and the use of modern methods of birth control (Banister and Hill 2004).

----- Figure 3 is here ----

It is believed that mortality will continue to decline in the oncoming years in China for the following two reasons. Firstly, there is room for decline. Life expectancy was 73.33 years for female and 69.63 years for male in 2000, which is far behind that in the European Union (2002: 81 years for female and 75 for male; Eurostat 2005: 80) and Japan (2004: 85.58 years for female and 78.66 for male; Human Mortality Database 2006) currently. Secondly, there is no indication that the record life expectancy will slow or stagnate in the near future (Oeppen and Vaupel 2002; Alho et al. 2006). Therefore, the changes during 1973-75 to 2000 are used to calculate the rates of initial decline for age-specific mortality (Figure 4: rate of initial decline). For forecasting purposes, the rates of initial decline were smoothed (using the "Running Median Smooth" procedure) and they were restricted to be positive. Mortality has continued to decline fastest at the youngest ages. In the working ages, the mortality decline for females exceeded the decline for males. At old ages, mortality decline was small compared to other age groups, and the gender difference was rather small. Rate of initial decline (Figure 4) also indicates that the increase of life expectancy at birth in China during the past three decades was mainly due to the decline in infant, children and adult mortality rather than the decrease of mortality among older people.

----- Figure 4 is here ----

As known from empirical evidence, when mortality at younger ages reaches a very low level, further decline becomes much more difficult to achieve. Then, improvement against mortality at older ages is likely to become the dominant force in the increase of life expectancy (Olshansky and Ault 1986). This is currently the case in many European countries such as Germany, Sweden and Finland. Here, it is assumed that the pattern of mortality decline in China in 2050 will closely resemble the pattern shown by European countries in the recent past (Figure 4: rate of ultimate decline). This seems plausible because of epidemiological transitions changing the age distribution of deaths (Horiuchi 1997). That is, the rates of decline at younger ages, especially children and younger women, will decrease and the rates of decline at older ages will increase.

Because the estimated initial rates of mortality decline for adult males are very low, much scope for improvement in the future exists. Adult women's rates of mortality decline have already reached a relatively high level; therefore, the potential for a further decline is decreased. Additionally, rates of mortality decline might decrease because underemployment, which is likely to affecting women stronger than men, might lower relative female social status in the near future. As a result, the gender differences in mortality decline will become smaller at younger ages. At older ages, both males and females are expected to experience higher rates of mortality decline, because new cohorts of the elderly may be healthier than older ones due to the improvement in living standards and medical progress, but biological gender differences may result in somewhat higher rates of decline for females than for males. The graph of rate of ultimate decline illustrates the smoothed rates of decline pattern for age-specific mortality (using Running Median Smooth) in current European countries, which have been used as the rates of ultimate decline in the forecast.

As for fertility, due to lack of long time-series data on age-specific mortality, the error terms estimated by Alho and Spencer (2005) for nine European countries (Austria, Denmark, France, Italy, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom) were borrowed. Those data end in 2000 and start at various times, the earliest being the United Kingdom in 1841. This was also a period of high volatility of mortality. For China the scale is again adjusted to a lower level because of the large level of heterogeneity in the population (Alho and Spencer 2005; Bongaarts and Bulatao 2000: 210, 339). The relative error in 2050 is thus calculated as 0.32. The resulting 80% and 95% predictive intervals for life expectancy are plotted in Figure 5.

According to the forecast distribution, life expectancy at birth for both sexes will increase linearly at a rate of about 2 years per decade. In 2050 females are expected to enjoy a life expectancy of 84.88 years and males one of 79.72 years. The 80% prediction interval, for males will be [77.20, 82.20] in 2050, covering a range of 5 years (6.3% of the median estimate); for females it will be [82.50, 87.3] in 2050, covering 4.8 years (5.7% of the median estimate). The 95% prediction interval at 2050 covers more than 6 years for both sexes.

Figure 5 also compares the forecast of life expectancy to the medium scenario projection of the UN. The UN forecasts have traditionally been rather conservative in predicting progress against mortality and have generally underestimated future life expectancy (Keilman 1998; Bongaarts and Bulatao 2000). Moreover, the forecast of life expectancy in this study seems to be plausible considering the reinstatement of social security, especially the health-care system at the national level, which has already been pronounced as one of the most important tasks by the Chinese government for the set goal of "Building a Harmonious Society" until 2020.

----- Figure 5 is here ----

International migration

Based on the 1990 census and the 1995 1% sample survey, emigration from China in 1995 was about 236,800 (Liang 2001). In 2000, the net migration rate for China was -0.3 migrants per 1,000 of population. This amounted to a loss of approximately 381,000 people.[9] This means that the net migration as a percentage of the total inhabitants was only 0.03%. The UN forecast predicts that net annual migration will decrease from 390,000 to 320,000 in 2050.[10] This forecast was used for point estimates in this projection.

In contrast to fertility and mortality, the uncertainty of international migration is represented in absolute numbers. Its autocorrelation across years was assumed to be constant. Analogous to fertility and mortality, the error terms for migration were borrowed from Europe, in this case 18 European countries (Alho and Nikander 2004). Again, based on empirical evidence it was assumed that China with its huge population and hence large heterogeneity should be buffered well against large shifts in migration (Alho et al. 2006: 261). Therefore it seemed appropriate that the scale values S should be set relatively low. The resulting assumption of net migration with its associated uncertainty is shown in Figure 6. Negative values of net migration indicate a net out-migration, i.e., when more people are leaving the country than entering it. In 2050 the 80% uncertainty interval ranges from -39 to +6 million and the 95% bounds are at -46 and +12 million.

----- Figure 6 is here ----

Indicators of population change

Certain demographic indicators are especially suitable to describe changes in population size and structure. Period life expectancy gives the average lifespan of an individual if the current mortality conditions were to persist through life. The changes in the structure of the population over time can be visualized by population pyramids and the following measures of population structure:

----- Table 2 is here ----

The division between male and female population is given by the sex ratio, defined as the male population divided by the female population.

Results

Total population size up to year 2050

The median of the forecast distribution projects China's total population to increase from the jump-off level of 1260 million at the end of 2000 to its maximum level at 1361 million people in 2024, and thereafter predicts it to decline to 1243 million people in 2050 (Figure 7: total population). Note that due to the large number of simulation runs (3000), the mean and median are equal. The long increase despite the well-below replacement TFR is likely due to a strong population momentum.

There is considerable uncertainty attached to the median estimates, including temporal as well a magnitude effects. The upper 80% prediction interval suggests an increase up to 1430 million people in 2040, whereas the lower one estimates a peak population of only 1314 million in 2020. In 2050 the 80% prediction interval covers a range of 1090 to 1419 million (i.e., 26% of the median estimate). Compared to the Chinese population forecast of the United Nations World Population Prospects in 2004, the predictions lie for the largest part between the low and medium variant scenario. The difference is mainly due to the fact that the UN assumed a higher TFR, i.e., 1.85 (median variant) by mid-century, while we expect it to stabilize at 1.47 after 2004. Furthermore, the UN used rather conservative mortality assumptions underlying their population projection.

The projected population development differs slightly for males and females. Whereas the male population will peak at 700 million in year 2023, the female population will reach its maximum size in 2025 at 661 million. Figure 7 shows that the gap between the number of males and females closes towards the end of the projection period, as females enjoy lower mortality at working ages and old ages.

----- Figure 7 is here ----

Age-sex structures

The population pyramids in Figure 8 illustrate the evolving age-sex structure over the projection interval, visualizing the rapid rate of population aging. From the predominance of the childhood and working age class in current China, it is predicted to shift to an age-structure characteristic of aging populations in Europe.

----- Figure 8 is here ----

The population snapshots shown in Figure 8 depict how the uncertainty spreads from the youngest age classes along the age axis over the forecast period. For the old age classes, the slower growth of uncertainty reflects the lower initial level of uncertainty for mortality. This can be understood easily since the younger age classes are born during the forecast years, while the older ones were already born before 2000. As a result, the younger age classes have a larger attached uncertainty than the older ones. After 50 years, the predictive distribution of the Chinese population composition ranges from a column-like to a rather regressive age pyramid, with most of the uncertainty attached to the base of the pyramid.

The rapid pace of population aging in China can also be seen in other indicators of population age-structure (Table 3). Life expectancy will increase consistently for both sexes (see Figure 5). Due to steady improvement in mortality rates, the proportion of elderly (65+) is expected to increase nearly four-fold during the next 50 years from about 7% [6.96, 6.98] in 2001 to 29% [24.4, 32.4] in 2050 – almost one third of the population. Combined with the continuously below-replacement level of fertility, the decline in mortality will raise the aging index even faster: a nine-fold increase from 28 [28.1, 28.3] in 2001 to 253 [152, 409] in 2050 is predicted. The median age of the total population increases from age 31 [31, 31] in 2001 to 52 [46, 56] in 2050.

----- Table 3 is here ----

Table 4 shows the temporal development of sex-specific indicators of population age structure. The gender gap in life expectancy is predicted to increase moderately from 3.7 years in 2000 to 5.2 years in 2050. Due to the lower age-specific mortality rates in females, by 2050, the age-sex-structure is expected to be highly asymmetrical with a sex ratio of 0.8 [0.74, 0.86] among the elderly and 0.6 [0.50, 0.71] among the oldest-old. As a further consequence, the gender differential in aging will increase rapidly. While the median age of males and females is currently identical, by 2050, a gender gap of 4 years is expected to have opened up. Also, in absolute numbers the female older and oldest-old population increases much faster compared to those of the males, with the differentials being largest for the 80+ population.

----- Table 4 is here ----

Old age dependency ratio

There remains no uncertainty to the fact that the OADR in China will rise steeply over the next 50 years (Figure 9): the median of the predictive distribution suggests a more than four-fold increase from 0.102 to 0.474 – from a level typical for Asian countries to one comparable to that expected in more developed countries such as Australia (Wilson and Bell 2004). Due to the highly biased sex-ratio at birth (1.17) and the lower mortality of females in working ages, the absolute numbers of population size for the ages 65+ and 80+ increases much faster for females than for males.

To evaluate how robust the OADR results are to the specific assumptions made in the forecast, they are compared with the OADR forecast of the UN. Regarding parameters of population aging, the OADR of 0.47 [0.41, 0.55] in 2050, predicted by the forecast in this study lies even above the low variant of the UN projection (upper grey dashed line in Figure 9). The higher fertility assumption of the UN and a potential bias in the predicted mortality decline may result in a lower OADR (Li, Lee, and Tuljapukar 2004).

----- Figure 9 is here ----

Probabilistic forecasts for 18 European countries predict a total European OADR of 0.57 in 2050 (Alho et al. 2006). Note however, that Alho et al. use a slightly different definition of the OADR for the European forecast, namely, using age group 20-64 instead of 15-64 as denominator. If that definition were applied in this study, the forecasted OADR would increase to 0.51 [0.44, 0.58] and be even closer to the OADR of the European countries in 2050.

It is important to note though that for the European countries, in the period 2000 to 2050, the OADR as defined above will double from 0.28 to 0.57. As mentioned before, China will reach a level of 0.51 in 2050, using the Alho et al. (2006) definition, but starts off from a much lower level, namely around 0.1 in 2000. Hence the OADR will multiply by 5.1 over the 50 projection years. This means that the pace of aging is more than twice as fast in China as in Europe.

The oldest-old (80+) class will expand even more rapidly than the total old age class (65+) (Figure 10). According to the median of the projection, the oldest-old dependency ratio (OODR) will multiply by more than 10 for both sexes; from 0.014 in 2001 to 0.15 in 2050. Figure 10 shows a sharp increase after 2040 that can be explained by the baby-boom cohort born in the 1960s that will reach the oldest-old class in 2040. (See also Figure 1).

----- Figure 10 is here ----

Discussion

This paper reports the results of a stochastic population forecast for China until 2050 with a focus on the process of population aging, and quantifies the expected uncertainty. Data limitation is a big challenge in projecting the Chinese population. Thus, in this study forecast errors estimated for some European countries with long-term and reliable historical data were borrowed, and some adjustments on scales were made, taking the large size and heterogeneity of the Chinese population into consideration. The relative error of the total population at the lead time of 50 years (i.e., in 2050) matches the one estimated by Bongaarts and Bulatao (2000: 210, 339). The rationale behind this paper is to make use of all available empirical sources to forecast the population stochastically, while acknowledging the uncertainty of the estimates, resulting from the country's lack of data. The key result of this study is that while there is considerable uncertainty attached to the predicted development of Chinese population size over the next 50 years, there can hardly be any doubt that the Chinese population is aging quickly. The proportion of the elderly population and the OADR will increase rapidly, which will lead to a heavy burden of support for the huge elderly population in China.

Population aging is certain in China 2001-2050

The extremely rapid pace of population aging in the first half of this century is the most important and worrisome development in China. By mid-century, with 80% probability the OADR will lie between 0.41 and 0.55, with the median of predictive distribution being 0.47, nearly five times the current number. This rapid population aging process results from the steep fertility decline since the 1970s (assuming TFR=1.47 remains constant from 2004 to 2050) on the one hand, and progress against mortality on the other. While the extraordinary fertility decrease since the 1970s has produced smaller cohorts of young people, the improvement in mortality decline will enable the large baby-boom cohorts born in the 1950s, 1960s and early 1970s to survive to old age. The increase in the OADR is the main factor leading to concerns about the sustainability of public old-age pensions (Alho et al. 2006).

Between 2001 and 2050, the population of the oldest-old will grow faster than any other age group in China. The OODR will be ten times as large compared to its current value (from 0.014 to 0.15). In 2050, with 80% probability the OODR will lie between 0.11 and 0.19. The share of the oldest-old to the elderly will increase sharply, especially after 2040 when the 1960s baby-boom cohort enters the oldest-old class. Moreover, due to the huge population in China, the absolute size of the oldest-old class is very large. Members of this class differ from those of the young-old class: they are much more likely to have extensive co-morbidity, and the decline of their functional ability accelerates with age (Baltes and Smith 2003; Fries et al. 2000; Zeng et al. 2002). Thus, they consume amounts of services, benefits and transfers far out of proportion to their population share (Suzman, Willis, and Manton 1992). Taken together, this indicates the necessity to prepare for providing sufficient care giving, services, benefits and transfers for this rapidly growing part of the population.

It should be recalled, however, that one of the forecasting assumptions used was that the ultimate rates of decline in mortality will be equal to those in European countries currently. In case China does not achieve the same rates of decline in mortality as Europe, the current results for population size, life expectancy and OADR will be somewhat biased high. The reasoning behind this assumption is two-fold. The first is the lack of relevant data to estimate the ultimate rates of mortality decline. The second is that, based on the epidemiological transitions, the mortality decline of current European population represents a plausible trend in the mortality decline of the future Chinese population. How far the other crucial assumption of the forecasting scenario will be met, that is, the constant below-replacement level of TFR=1.47, will largely depend on Chinese fertility policy decisions in the oncoming years.

This forecast points towards severe disadvantages for elderly women in China. Because females have a higher life expectancy than males, the share of older females in the population is larger and increases faster than for males. Moreover, this gap increases over age and the projected time period (see Table 4). Some previous studies have shown that elderly Chinese women are much more likely to be widowed and economically more dependent (Zeng and George 2000). At the same time, the social security for them is much poorer than for their male counterparts (Jia 2006). In short, women’s quality of life in old age will be at risk.

Policy implications

Facing such a dramatically rapid pace of population aging, what are the measures Chinese decision-makers should consider? Potential counter-strategies should address the causes as well as the symptoms of population aging, i.e., including adjustments of fertility policies and elderly support systems.

China should smoothly adjust its current birth control policies toward a less restrictive one that allows more couples to have more than one child. The present fertility assumptions, i.e., a TFR of 1.47 and a SRB of 1.17 until 2050, are mainly based on the current birth control policies. The future elderly of the forecasting period have been already born, but an increase in fertility would result in a higher percentage of people in the working ages. At the macro level, this would increase the denominator and thus reduce the OADR. At the micro level, adjusting fertility policy would also be helpful in reducing adult children's burden in the support of their elderly parents because there will be siblings to share the load. It is important to remember that in China, due to its huge population, any change in population policy could result in large absolute changes. Thus, any adjustment should be planned very carefully. How to adjust the fertility policy exactly is beyond the present research. Further forecasting that focuses on policy making could help to evaluate potential effects of different fertility policies on population aging.

In today's China, the family support system which has worked for thousands of years still plays the dominant role on supporting the elderly. Old age insurance programs are insufficient and poor, especially in rural areas. China has not yet found a good model to build up a functioning old age insurance program. More than 20% of urban residents have no social security at all, and the remainder of the urban population is covered by inadequate social security. The majority of rural residents are without any social security at present. Thus, in the next 50 years, besides continuing to encourage family support through rewarding people who live with their old parents by measures such as adequate tax exemption and favorable housing policy, China should devote resources to establish age insurance and healthcare programs. Fortunately, the Chinese government has now realized that the lack of a sufficient social security system will impede sustainable development in China. Establishing a functioning social security system is one of the most important tasks in the set goal of "Building a Harmonious Society" by 2020. As discussed here, the severe disadvantages elderly women are confronted with require special attention from family, society and government. Old age insurance programs should benefit older women and men equally, and care services should take elderly women's poorer health and economic status into account.

Acknowledgements

The authors would like to thank Jutta Gampe (MPIDR), Joop de Beer (NIDI) and Beata Nowok (NIDI) for constructive comments on an earlier draft. For valuable language editing, we would like to thank Susann Backer.

TABLE 1 Sources of the data used in the forecast

Forecast parameters	*Data sources*
Jump-off population	2000 census, and adjustments by Wang (2004)
Fertility	
Jump-off values for age-specific fertility rates and TFR	2000 census
Annual TFR, 1950-2000	Fertility surveys conducted by SFPC
	Yearly data from NBS
	2000 census
Mean age at childbearing	2000 census, Guo (2004)
Mortality	
Jump-off values for age-specific mortality rates	2000 census
Rate of initial declines	Cancer Epidemiology Survey (1973-1975)
	1982 census
	1990 census
	2000 census
Rate of ultimate declines	Current European rates (from BEGIN program)

TABLE 2 Measures of population aging and their definitions

Measure	*Definition*
Proportion of elderly	population 65+ / total population
Aging Index	population 65+ / per 100 of population 0-14
Old Age Dependency Ratio	population 65+ / population 15-64
Oldest-old Dependency Ratio	population 80+ / population 15-64
Median age	median age of the total population

TABLE 3 Population aging: temporal development of age structure indicators

Demographic indicator	*2001*	*2020*	*2035*	*2050*
Life expectancy at birth	71.6	75.6	78.8	82.3
	[71.4, 71.9]	[74.4, 78.6]	[77, 80.6]	[80.0, 84.7]
Proportion of elderly	0.070	0.120	0.213	0.286
(65+ / total population)	[0.070, 0.070]	[0.114, 0.125]	[0.195, 0.230]	[0.244, 0.324]
Aging index	28.2	75.3	170.6	253.4
(65+ / (0-14 / 100))	[28.1, 28.3]	[63.0, 88.8]	[124.5, 228.8]	[152.2, 408.9]
Median age (total	31	39	46	52
population)	[31, 31]	[38, 40]	[44, 48]	[46, 56]

TABLE 4 Sex-specific indicators of population aging

	2001		*2035*		*2050*	
Indicator	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
Sex ratio total population (M/F)	1.069 [1.069, 1.070]		1.045 [1.030, 1.061]		1.033 [1.003, 1.060]	
Sex ratio 15-64 (M/F)	1.068 [1.067, 1.068]		1.097 [1.087,1.106]		1.134 [1.119, 1.147]	
Sex ratio 65+ (M/F)	0.879 [0.878 ,0.879]		0.840 [0.797, 0.881]		0.804 [0.743, 0.864]	
Sex ratio 80+ (M/F)	0.590 [0.588, 0.591]		0.602 [0.513, 0.686]		0.604 [0.496, 0.712]	
Life expectancy at birth	69.8 [69.5, 70.0]	73.5 [73.3, 73.7]	76.3 [74.3, 78.2]	81.4 [79.5, 83.2]	79.7 [77.2, 82.2]	84.9 [82.5, 87.3]
Median age	31 [31, 31]	31 [31, 31]	45 [42, 47]	48 [46, 49]	50 [44, 54]	54 [49, 58]
Population size 65+ (millions)	41.3 [41.2, 41.4]	47.0 [46.9, 47.1]	129.2 [118.0, 140.1]	153.8 [143. 8,163.3]	156.5 [136.2, 176.8]	194.6 [176.1, 213.0]
Population size 80+ (millions)	4.6 [4.5, 1.6]	7.7 [7.7, 7.8]	20.2 [15.3, 25.5]	33.6 [27.8, 39.5]	41.7 [30.0, 55.2]	69.4 [56.0, 83.6]

FIGURE 1 Total fertility rates in China in 1950-2000 and future trajectory of point TFR assumed in the forecast

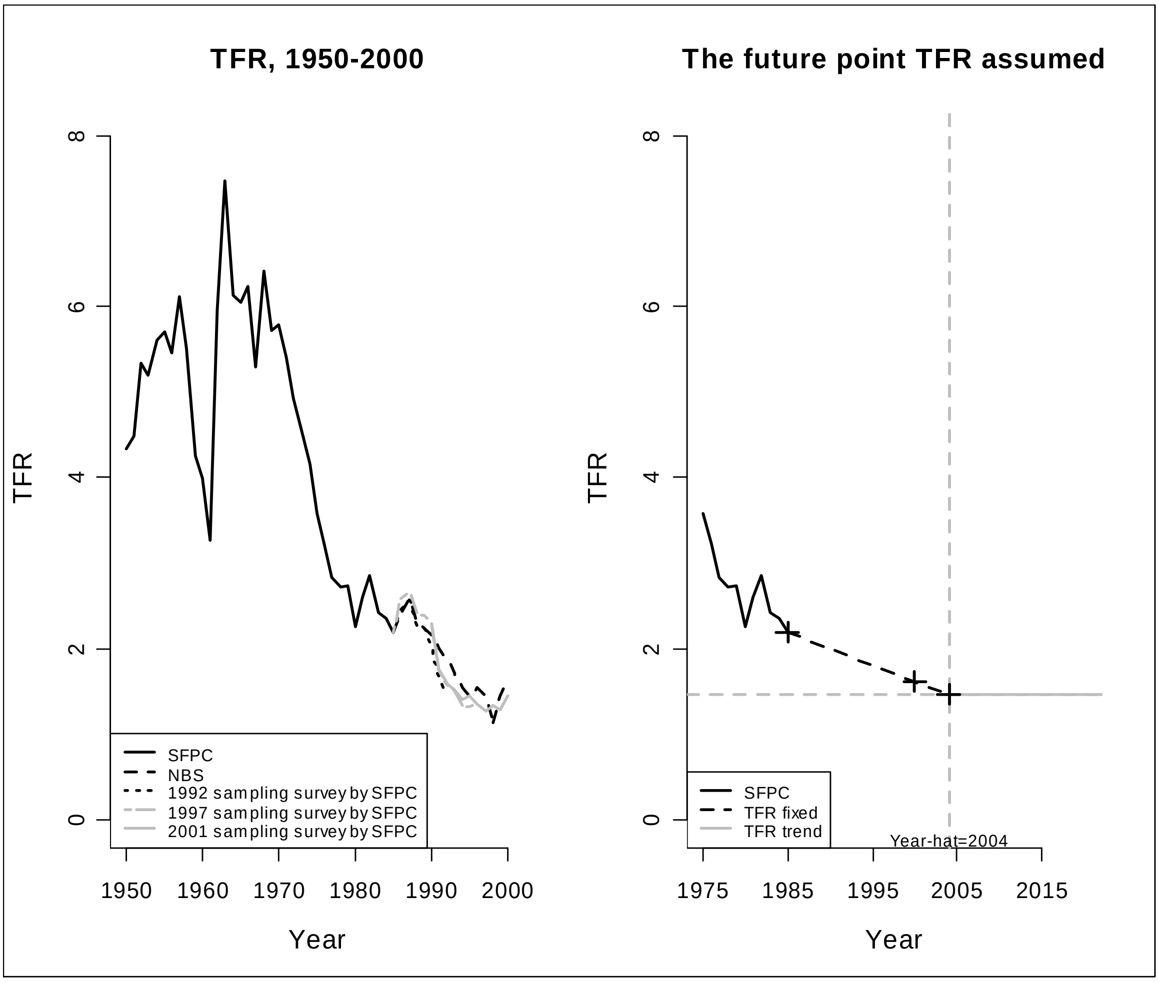


FIGURE 2 Estimated developments of total fertility rate and prediction interval bounds

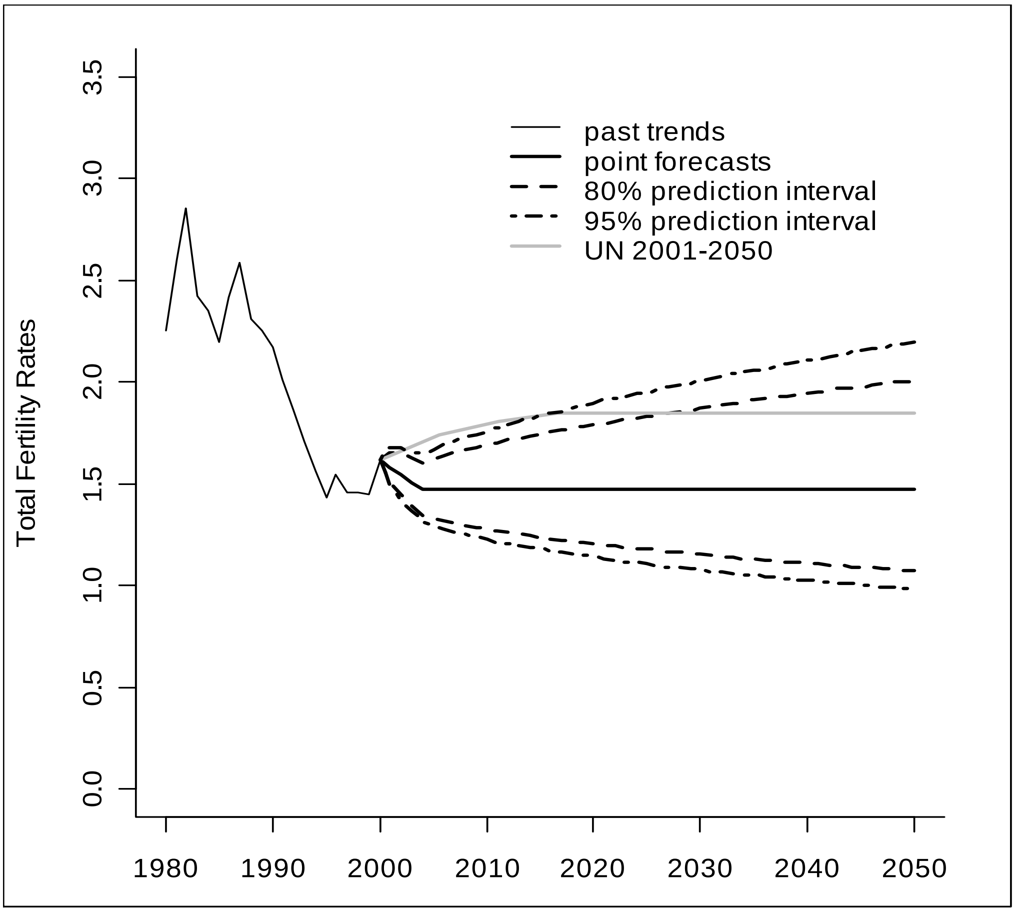


FIGURE 3 Observed log(m_x) at ages 0-89 and extrapolated log(m_x) at ages 90-100+ for males and females, based on Kannisto model fitted to available data

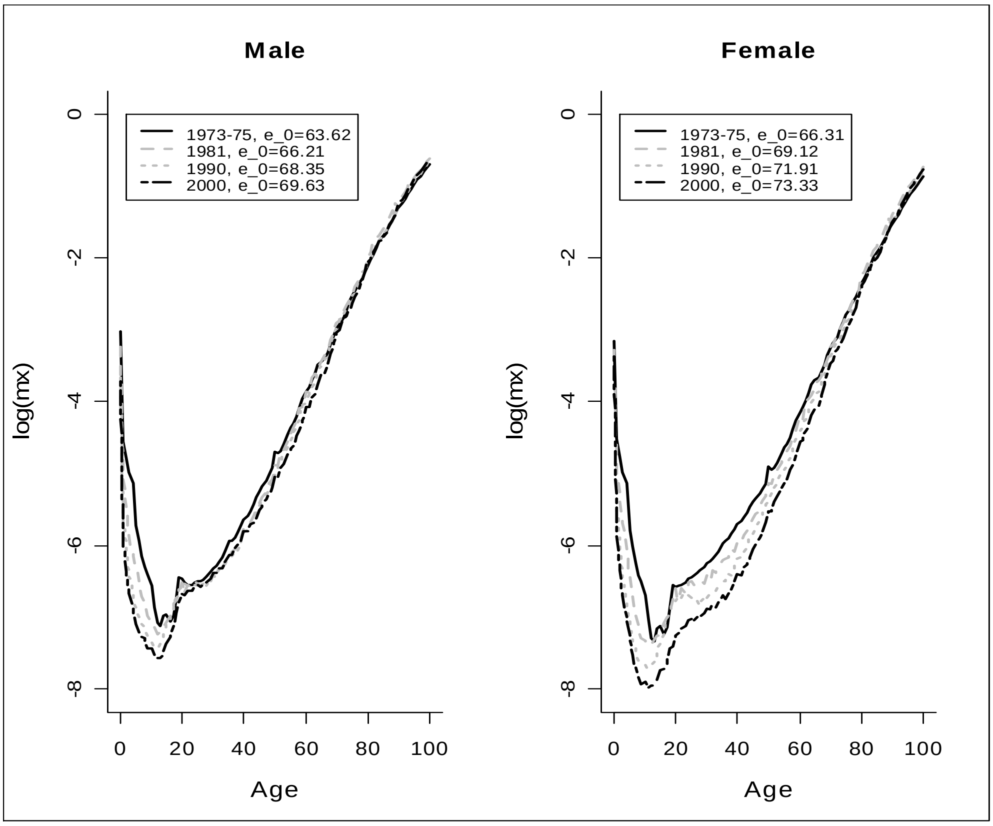


FIGURE 4 Smoothed rates of decline in age-specific mortality used in the forecast. Rate of initial declines were estimated using Chinese data available. Rate of ultimate declines were borrowed from European countries.

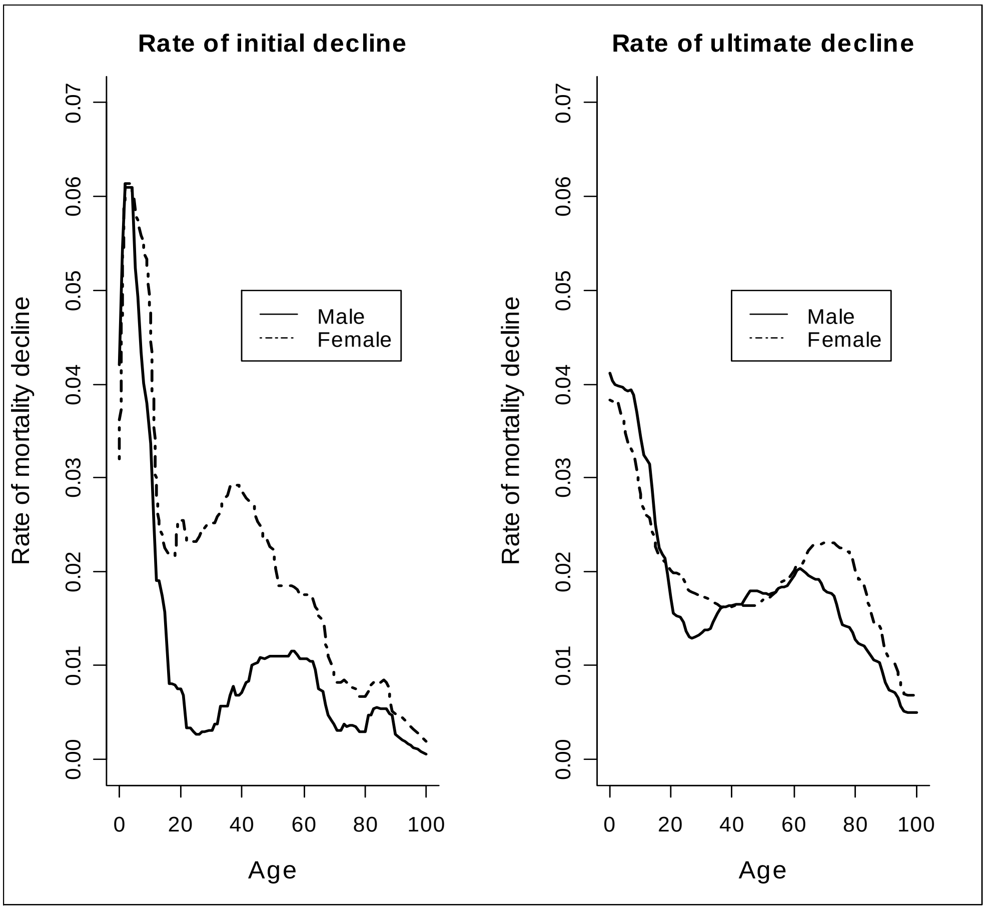


FIGURE 5 Estimated life expectancy at birth and prediction interval bounds for males and females

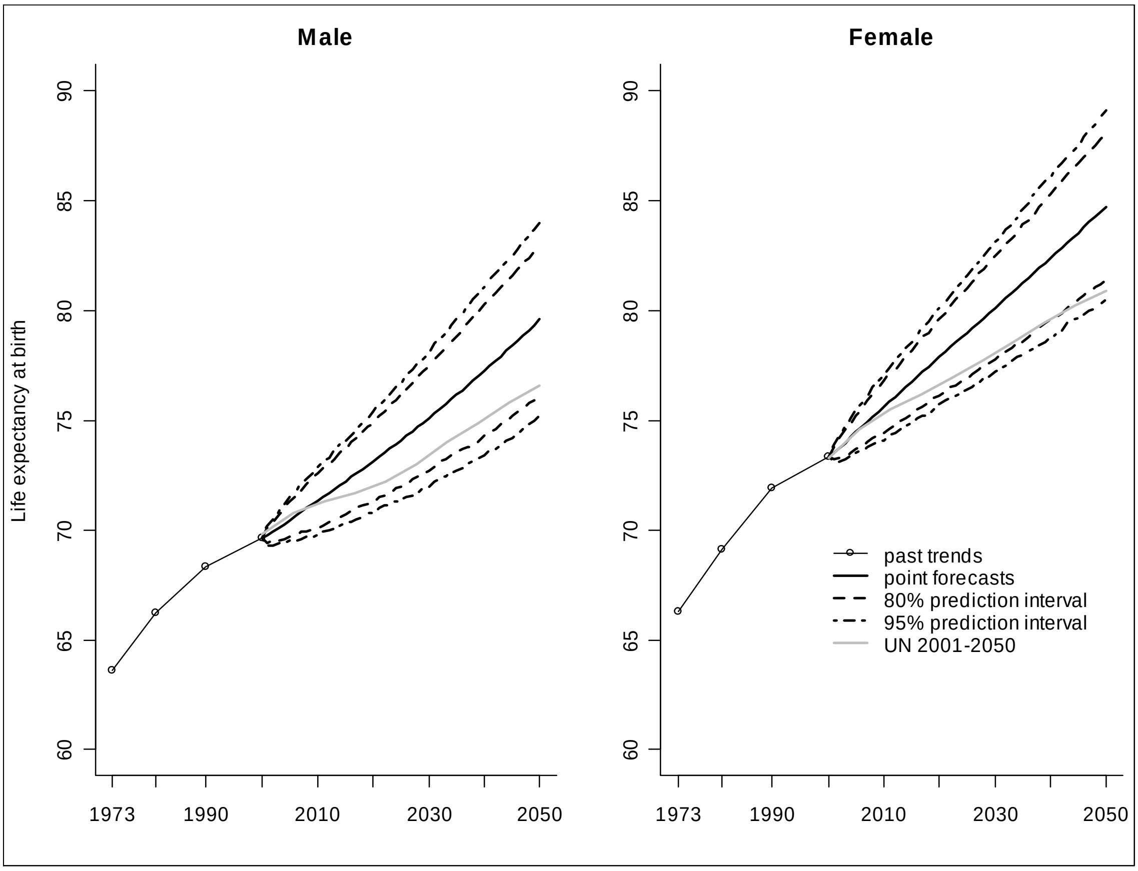


FIGURE 6 Forecasted net cumulative migration in millions, China 2001-2050

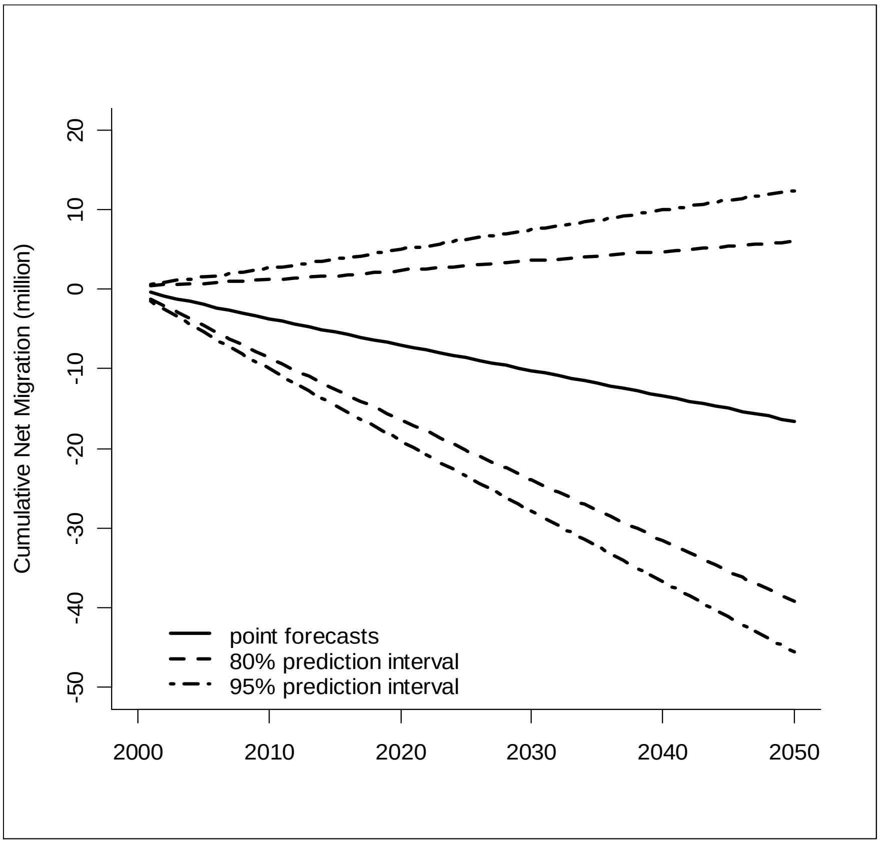


FIGURE 7 Projected development of China's total population in millions and 80% prediction intervals compared to UN high, medium and low variants and male and female population in millions, 2001-2050

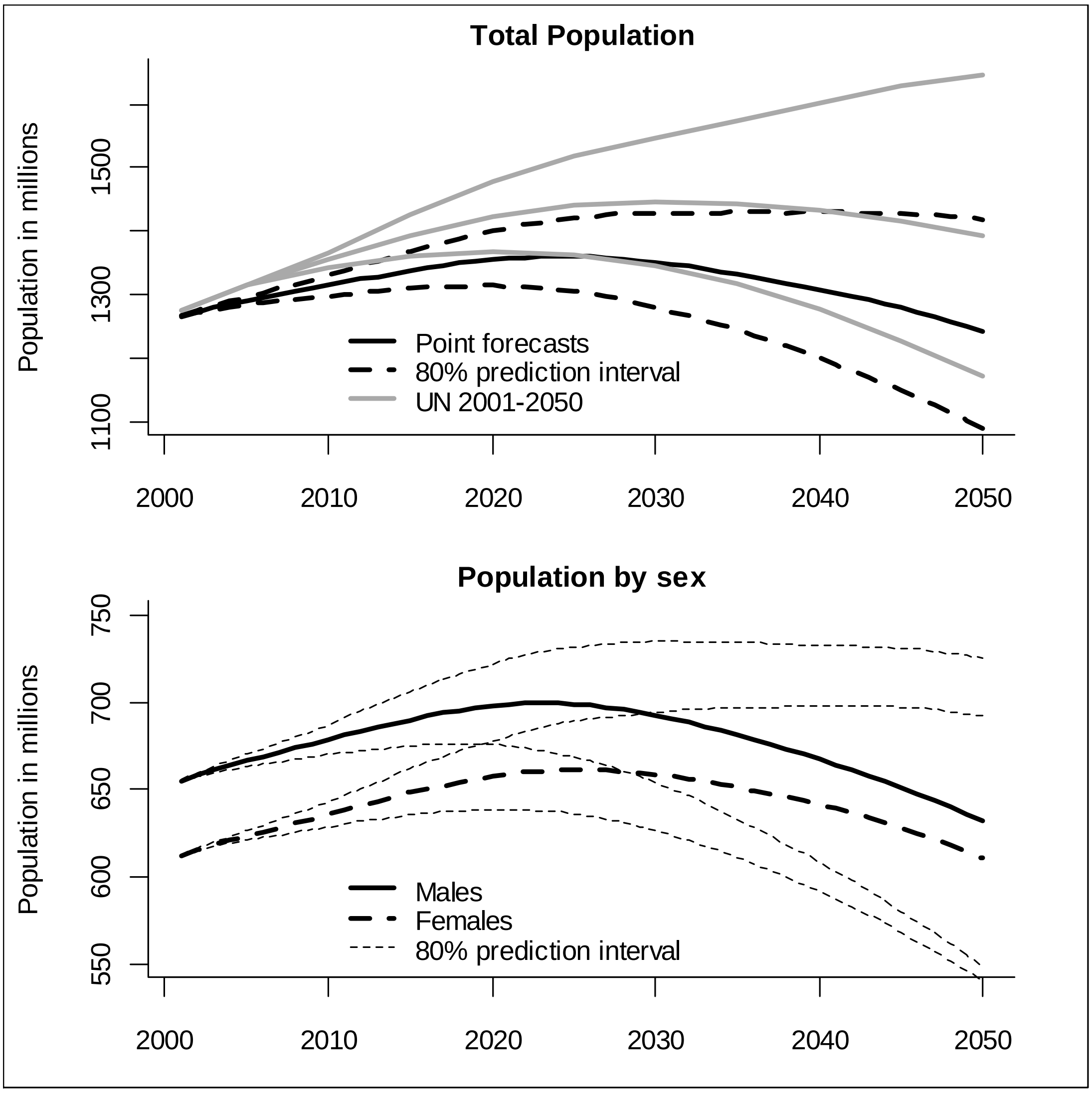


FIGURE 8 Population pyramids for 2001, 2025, 2035 and 2050 and 80% uncertainty intervals. Inner pyramid shows lower boundary (10%) and black the upper boundary (90%) of the 80% uncertainty interval

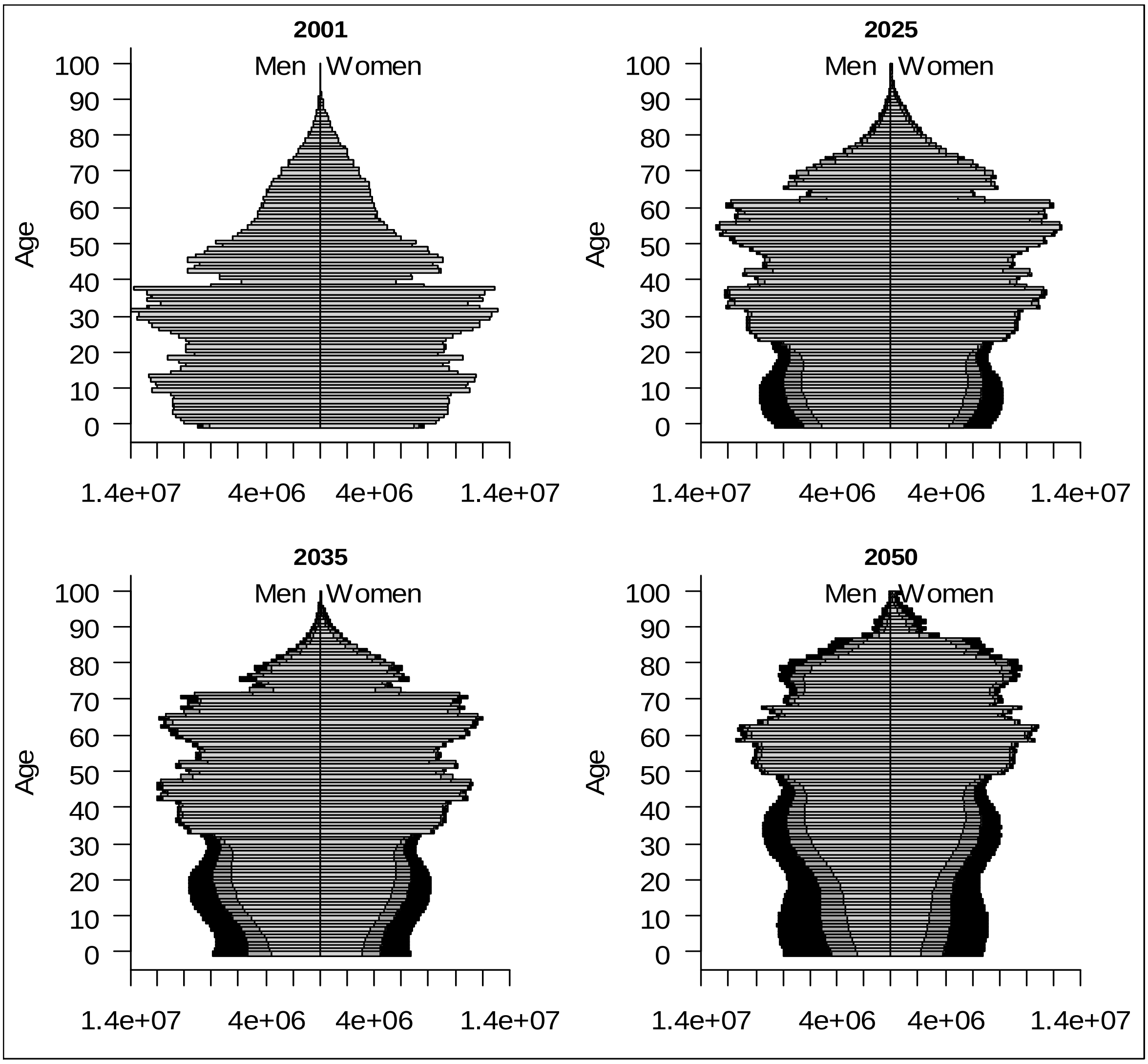


FIGURE 9 Predicted OADR and 80% prediction intervals, compared to UN forecasts low, medium and high variants. (UN high variant gives the lower OADR).

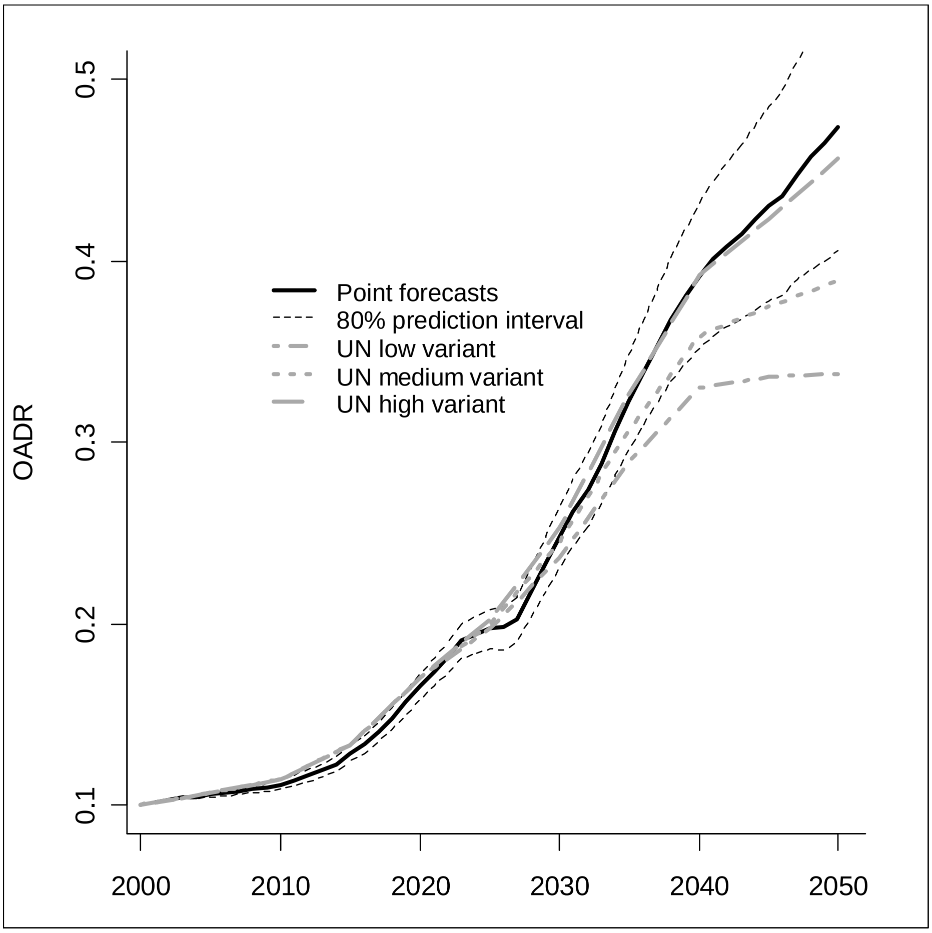
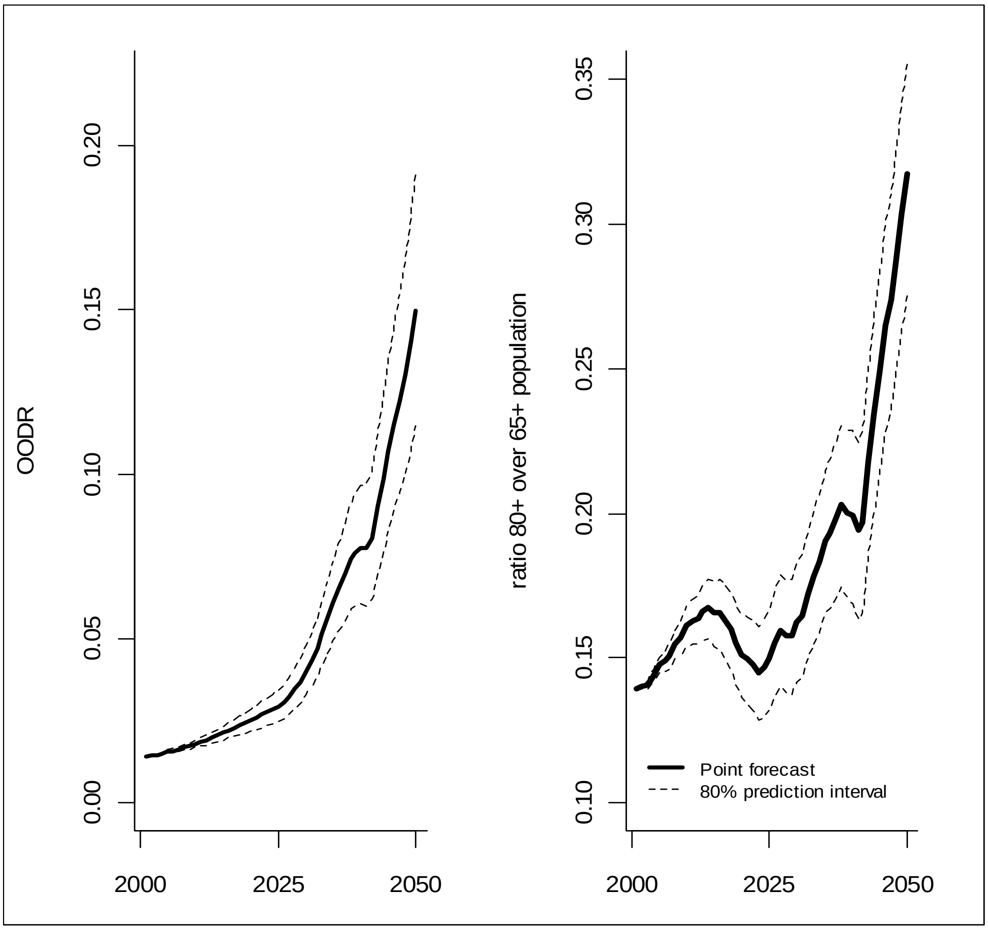


FIGURE 10 Total predicted OODR, and predicted ratio of 80+ population over 65+ population, China 2001-2050



Notes:

[1] Most developed countries have used the age of 65 to define old age. In China, the definition of old by law is based on the retirement age. Currently, the official retirement age for Chinese males is 60 and for females it is 55. Accordingly, some Chinese scholars use the age of 60 to calculate their statistical results. For the sake of comparability to other countries, the present paper uses the age of 65 and over.

[2] Currently, in cities, if both wife and husband are single-child, they are allowed to have two children.

[3] In the 2000 census, time and space standard for permanent residents were adjusted, compared with the previous census in 1990. The time standard for permanent residents was reduced from one year to six months. The space standard was also reduced from county (city) to township (street) in order to reflect the increased mobility in the population.

[4] In order to project the population forward to 31 December 2000, the mortality probability (q_x) from the life table in 2000 was used, which is easily converted to a two-month probability:

$$q_{x((nov-dec)} = q_{year}^{61/365}.$$

In case the mortality in November and December 2000 was in fact higher than during the remainder of the year, the estimated mortality probabilities will be underestimated and the jump-off population estimates will be slightly biased upward.

Analogously, for fertility, the number of births was assumed to be constant over the months of the given year. Therefore, birth numbers in November and December were obtained by simply multiplying the number of births in a year by *61/365*. These births were then “survived” until 31 December 2000.

[5] In the current application, the Karup-King formula for interpolation caused unreliable results for the first ages, which is also explained in Shryock (1976). The Karup-King coefficients resulted in negative ASFR for the ages 15 and 16, which is of course impossible. Therefore, the ASFR by single years from 1992 were used to obtain the distribution of ASFR between ages 15 and 19. Finally, the single-year ASFR from age 15 to 49 years were applied in PEP as a basis for the forecast.

[6] For estimates of target TFR see the article by Gu et al. (2007) in *Population and Development Review.*

[7] Birth control policies have been adjusted to some extent to avoid the 4:2:1 family structure (4:2:1 family structure is 4 grandparents, 2 parents and 1 child). For example, if both parents are single children, they are allowed to have two children.

[8] Three models were examined to describe the hazard function for China: (1) Gompertz, (2) logistic and (3) Kannisto. The latter two were considered because existing evidence suggests that at older ages the increase in mortality decelerates (Thatcher, Kannisto, and Vaupel, 1998). Models were fitted using maximum likelihood estimation; model selection was based on Akaike's Information Criterion (AIC) as described by Burnham and Anderson (2002). For each year-sex combination, the Kannisto model was strongly supported by the data.

[9] See www.nationsencyclopedia.com/Asia-and-Oceania/China-migration.html

[10] UN World Population Prospects: The 2004 Revision.

References

Alders, M., Keilman, N., and H. Cruijsen. 2007. "Assumptions for long-term stochastic population forecasts in 18 European countries." *European Journal of Population* 23(1): 33-69.

Alho, J.M., Alders H.C., Keilman, N., Nikander T. and D.Q. Pham. 2006. "New forecast: population decline postponed in Europe." *Statistical Journal of the United Nations* ECE 23:1-10.

Alho, J. M. and M. Mustonen. 2003. *Tutorial for PEP - Program for Stochastic Forecasts of Population* [online]. Available from < http://www.joensuu.fi/statistics/pep/peptutorial.pdf#search=%22Alho%20Mustonen%20PEP%22> [accessed 24 August 2007].

Alho, J. M. and T. Nikander. (2004) *Uncertain Population of Europe -Summary Results from a Stochastic Forecast.* [online]. Available from http://www.stat.fi/tup/euupe/rp_reports_and_pub.html [accessed 24 August 2007].

Alho, J.M., and B.D. Spencer. 2005. *Statistical Demography and Forecasting*. New York: Springer.

Baltes, P.B. and J. Smith. 2003. "New frontiers in the future of aging: from successful aging of the young old to the dilemmas of the fourth age." *Gerontology* 49(2):123-135.

Banister, J. and K. Hill. 2004. "Mortality in China 1964-2000." *Populations Studies* 58(1):55-75.

Bongaarts, J. and R.A. Bulatao. (eds.). 2000. *Beyond Six Billion: Forecasting the World's Population*. Washington, D.C: National Academy Press.

Borgy, V. and J.M. Alho. 2007. "Macroeconomic consequences of demographic uncertainty in world regions." In Alho J.M., Hougaard-Jensen S. and J. Lassila (ed.), *Demographic Uncertainty and Fiscal Sustainability*. Cambridge: Cambridge University Press. (to appear)

Burnham, K.B. and D.R. Anderson. 2002. *Model Selection and Multimodel Inference: a Practical Information-Theoretic Approach*. New York: Springer.

Chen, Sh.L. and Sh.K. Zhang. 2003. *Research on Contemporary People' Preference of Marriage and Childbearing: 2002 National Preference of Marriage and Childbearing Survey*. Beijing: China Population Publishing House.

Eurostat 2005. *Europe in figures - Eurostat yearbook 2005* [online]. Available from <http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1334,49092079,1334_49092421&_dad=portal&_schema=PORTAL> [accessed 24 August 2007].

Fries, B.E., Morris, J.N., Skarupski, K.A., Blaum, C.S., Galecki, A., Bookstein, F. and M. Ribbe. 2000. "Accelerated dysfunction among the very oldest-old in nursing homes." *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 55(6):M336-M341.

Griffith, F., Wang, F., Zhou M. and B. Xiao. 1989. “Recent fertility dynamics in China: results from the 1987 One Percent Population Survey”. *Population and Development Review* 15(2):297-322.

Gu, B.Ch., Wang, F., Guo, Zh.G., and E.L. Zhang. 2007. “China’s local and national fertility policies at the end of the twentieth century”. *Population and Development Review* 31(1):129-147.

Guo, Zh. G. 2004. “Fertility in China in the 1990s.” *Population Research* (Chinese) 28(2):10-19.

Guo, Zh.G. 2006. *Fertility since 1990s and its influence on China's future.* China Center for Economic Research (CCER) [online]. Available from <http://ccer.pku.edu.cn/cn/ReadNews.asp?NewsID=6131> [accessed: 24 August 2007].

Hesketh, T. and Z.W. Xing. 2006. “Abnormal sex ratios in human populations: causes and consequences.” *Proceedings of the National Academy of Sciences* 103(36):13271-13275.

Horiuchi S. 1997. “Epidemiological transitions in developed countries: past, present and future.” *Symposium on health and mortality. Brussels, Belgium, 19-22 November* 1997:237-254.

Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available from <http://www.mortality.org/> [accessed: 24 August 2007].

Jia, Y. Zh. 2006. *The Chinese elderly women*. Available from <http://www.china.org.cn/chinese/zhuanti/fnfzbg/1156283.htm> [accessed 24 August 2007].

Keilman, N. 1997. “Ex-post errors in official population forecasts in industrialized countries.” *Journal of Official Statistics* 13:245-277.

Keilman, N. 1998. “How accurate are the United Nations world population projections?” *Population and Development Review* 24:15-41.

Keilman, N. 2001. “Uncertain population forecasts.” *Nature* 412(6846):490-491.

Kahn, J. 2007. “Chinese riot over steps to control population” *International Herald Tribune* May 22:4.

Lee, R.D., & L. Carter. 1992. “Modelling and forecasting the time series of US mortality.” *Journal of the American Statistical Association* 87, 659-671.

Lee, R. and T. Miller. 2001. “Evaluating the performance of the Lee-Carter Approach to Modeling and Forecasting Mortality.” *Demography* 38(4):537-549.

Li, N., Lee, R. and S. Tuljapurkar. 2004. "Using the Lee-Carter method to forecast mortality for populations with limited data." *International Statistical Review* 72(1):19-36.

Li, Y. 2005. "The Challenges of Aging Toward Chinese Society." *Public Administration and Management: An Interactive Journal* 10(3):25-45.

Liang, Z. 2001. "Demography of illicit emigration from China: a sending country's perspective." *Sociological Forum* 16(4):677-701.

Lutz, W., Ren, Q., Scherbov, S., and X. Zheng. 2005. "China's uncertain demographic present and future." Paper presented at the Annual Meeting of the IUSSP, Tours, France, 18-23 July 2005.

Nie Y. and R.J. Wyman. 2005. "The One-Child Policy in Shanghai: Acceptance and internalization." *Population and Development Review* 31(2):313-336.

Oeppen, J. and J. Vaupel. 2002. "Broken limits to life expectancy." *Science* 296(5570):1029-1031.

Olshansky, S. J. and A. B. Ault. 1986. "The Fourth Stage of the Epidemiologic Transition: The Age of Delayed Degenerative Diseases." The Milbank Quarterly, 64(3): 355-391.

Parish, W.L. and M.K. Whyte. 1978. *Village and Family in Contemporary China*. Chicago: University of Chicago Press.

Population Census Office under the State Council and Department of Population, Social, Science and Technology Statistics, National Bureau of Statistics. 2002. *Tabulation on the 2000 Population Census of the People's Republic of China*. Beijing: China Statistics Press.

Retherford, R.D., Choe, M.K., Chen, J., Xiru, L. and C. Hongyan. 2005. "How far has fertility in China really declined?" *Population and Development Review* 31(1):57-84.

Riley, N.E. 2004. "China's population: new trends and challenges." *Population Bulletin* 59(2):3-36.

Shryock, H.S. 1976. *The Methods and Materials of Demography*. New York : Academic Press.

Suzman, R.M., Willis, D. and K. Manton. 1992. *The Oldest Old*. New York: Oxford University Press.

Thatcher, A.R., Kannisto, V. and J.W. Vaupel. 1998. *The Force of Mortality at Ages 80 to 120*. Odense: Odense University Press.

United Nations. 2005. *World Population Prospects. The 2004 Revision, Volume II: The Sex and Age Distributions of Populations*. NewYork.

Wang, G. Zh. 2004. "On data evaluation and adjustment for age structure of the fifth census of China." *Population and Economics* (Chinese) 5: 60-66.

Wang, F. 1996. “A decade of the One-Child Policy: Achievements and implications.” in Goldstein, A. and F. Wang (eds.) *China: The Many Facets of Demographic Change*. Boulder, Colorado: Westview Press: 97-120.

Wilson, T. and M. Bell. 2004. “Australia’s uncertain demographic future.” *Demographic Research* [online] 11:195-234. Available from http://www.demographic-research.org/volumes/vol11/8/11-8.pdf [accessed 24 August 2007].

Woo, J., Ho, S.C., Yuen, Y.K., Yu, L.M. and J. Lau. 1996. “An estimation of the functional disability burden in elderly Chinese age 70 Years and over.” *Disability and Rehabilitation* 18(12):609-612.

Woo, J., Kwok, T., Sze, F.K.H. and H.J. Yuan. 2002. “Aging in China: health and social consequences and responses.” *International Journal of Epidemiology* 31(4):772-775.

Yanulevskaya, V. and J. Alho. 2005. *Tutorial for BEGIN* [online]. Available from <http://joyx.joensuu.fi/~ek/pep/BeginTutorial.pdf#search=%22Tutorial%20for%20BEGIN%22> [accessed: 24 August 2007].

Yuan, X. and J.-C.E. Tu. 2005. *High sex ratio at birth and female deficit in China* [online]. Paper presented at the International Conference on "Female Deficit in Asia: Trends and Perspectives" Singapore, 5-7 December 2005. Available from < http://www.cicred.org/Eng/Seminars/Details/Seminars/FDA/PAPERS/19_YuanXin.pdf > [accessed 24 August 2007].

Zeng Y. 2006. Population Aging, *‘Two-Child Plus Spacing’ policy, and economic and social development in China.* China Internet Information Center [online]. Available from <http://ccer.pku.edu.cn/cn/ReadNews.asp?NewsID=6131> [accessed 24 August 2007].

Zeng, Y., Vaupel, J.W., Zhenyu, X., Chunyuan, Z. and L. Yuzhi. 2002. “Sociodemographic and health profiles of the oldest old in China.” *Population and Development Review* 28(2):251-273.

Zeng, Y., Liu, Y. and L.K. George. 2003. “Gender differentials of the oldest old in China.” *Research on Aging* 25(1):65-80.

Zeng Y. and L. George. 2000. Family dynamics of 63 million (in 1990) to more than 330 Million (in 2050) elders in China. *Demographic Research* 2:1-48.

Zeng Y. and J.W. Vaupel. 2003. “Oldest-old mortality in China.” *Demographic Research* [online] 8:215-244. Available from <http://www.demographic-research.org/Volumes/Vol8/7/8-7.pdf> [accessed 24 August 2007].

Zhang J. and L. Xiao. 1999. “Discussion on the reform direction of the social security system in China.” *Social Security System* 2:48-50.

Zimmer, Z. and J. Kwong. 2003. “Family size and support of older adults in urban and rural China: current effects and future implications.” *Demography* 40(1):23-44.