The Korean Economic Review
Volume 36, Number 1, Winter 2020, 201-225.

Impact of Longevity Risks on the Korean Government: Proposing a New Mortality Forecasting Model*

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Korea's life expectancy has experienced an unprecedented rapid increase that is significantly higher than that in other advanced economies. However, this phenomenon also signifies that the Korean government faces a considerable financial risk. This study identifies the factors that contribute to the overestimation of mortality and develops a new mortality forecasting model. In addition, the population projections of the new mortality forecasts are used to quantitatively measure the economic size of the longevity risks faced by the Korean government. Results suggest that if substantial longevity exposure is realized in the context of the Korean government, the longevity can solely increase the debt-to-GDP ratio by 33.8%p by 2060. Drawing on these findings, this study concludes with suggestions to mitigate such longevity risks.

JEL Classification: C14, H55, H68, J11
Keywords: Population Projection, Longevity Risk, Government Debt, Nonparametric Panel Regression

I. Introduction

In December 2015, the Korea's Ministry of Strategy and Finance (MOSF) addressed the aging population and released long-term fiscal expenditure

Received: Aug. 15, 2018. Revised: March 5, 2019. Accepted: June 30, 2019.
* The author is grateful for the beneficial comments from OECD-UNFPA-MOHW-KIHASA joint conference (2017), EcoSta 2017, the 74th Japan Institute of Public Finance conference (2017), 2016 Korea's Allied Economic Association Annual Meeting, and seminars from The Korean Econometric Society and The Korea International Economic Association. The author also extends gratitude to the two referees for their constructive comments. The author acknowledges that this work is an enhanced modification of the work, "Study on Measuring and Managing Longevity Risk", Korea Development Institute (2015). This research was supported by the Chung-Ang University Research Grants in 2017.
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projections until 2060 on the basis of changes in the long-term demographic and potential growth rates. The Korean government refers to these estimates to formulate and streamline related policies. However, these measures have possibly been based on consistently underestimated projections for the elderly population. The International Monetary Fund (IMF, 2012) states that the baseline population forecasts have consistently underestimated life expectancy in the past. The current study actually finds a downward bias in the Statistics Korea's long-term projections for the elderly population, and the magnitude of this bias in Korea is considerably more severe than that in developed countries in the IMF (2012) report. Accordingly, the fiscal expenditure is expected as considerably higher than the MOSF's 2015 projections.

Mortality forecast modeling has a long history since Gompertz (1825) published his law of human mortality. Since then, relatively simple models using the parametrization functional form including the models of Holigman and Pollard (1980), Coale and NcNeil (1972), and Siler (1983) have been adopted (Booth and Tickle, 2008). Life expectancy continues to escalate, and the importance of mortality forecasting has simultaneously been increased. Notably, sophisticated methods have been developed merely three decades ago. Among many stochastic models, the most successful models are the Lee–Carter (LC) (1992) model and its variants. Furthermore, Statistics Korea has also adopted the LC type models since the 2006 population projection.

However, the research on longevity risk are relatively limited. In Japan, efforts to manage longevity risk are apparently being exerted by improving the mortality forecasting model. Ishii (2013) proposed the shift model to predict the mortality rate of elderly and overcome the limitations of the LC model. In particular, LC model fails to accommodate the changing mortality improvement pattern. The Japanese government has adopted Ishii's model to estimate population since 2006. Since then, the prediction error of the elderly has been greatly reduced. As of 2014, the forecast error of elderly (aged 65 and over) from 2006 population estimate is merely −0.2%.[1]

Antolin and Blommestein (2007) measured the longevity risk for pensions in the EU countries and estimated that spending 0.3% of GDP would be necessary if the expected life expectancy increased by 1–1.5 years. The estimated unexpected increase in life expectancy is 1.1 years per decade, and 1.2% of GDP will be incurred by 2050.

In Korea, related studies have focused on the longevity risk of private sectors. Kim et al. (2012) assessed the longevity risk of domestic insurance companies and

[1] In USA, Lee and Miller (2001) evaluated the LC model's forecasting performance to conclude LC tended to overestimate the elderly's mortality, but by less than the Social Security forecast. The size of the forecast error of the elderly population in USA is apparently smaller than that in Japan when the LC model is adopted. This is because the aging process progresses much slowly in USA and the assumption of the constant age-specific mortality improvement is not critically violated.

emphasized the necessity of calculating premiums with consideration of the characteristics of life annuity subscribers and the demand to develop various pension products. Lim (2015) assessed the longevity risk of domestic insurance companies and examined the feasibility of issuing longevity bonds to manage longevity risk. However, no previous study on longevity risk of government is available.

This study focuses on the financial consequences associated with longevity risks,[2] that is, the risk of people living longer than expected from the viewpoint of the Korean government. This study initially identifies the factors that contribute to the consistent underestimation of population projections to build a new mortality forecasting model. Next, this paper uses the newly estimated population projections as input for long-term fiscal expenditure estimations to quantify the economic size of longevity risks for the Korean government.

Mortality rates, which determine life expectancy, tend to improve over time for each age group. However, the pace of improvement for each group's mortality varies by stage of economic growth. For instance, children's mortality rates significantly improve in the early phase of economic development, while those of the elderly improve prominently in an advanced economy.

However, Statistics Korea's population projections are based on a model that assumes a fixed mortality improvement pattern across the years. The model estimates the speed of mortality improvement across age groups using the data from 1971 to 2010 and offers the average improvement speed for the sample period. The mortality rates are forecasted by age assuming that the improvement speed will remain the same average speed in the future. Given that the mortality improvement pace for the elderly population accelerates with rapid economic growth, Statistics Korea tends to over-forecast the mortality rates of the elderly. Consequently, the projections for the elderly population would be under-forecasted.

This paper proposes a new mortality prediction method to allow mortality improvement patterns evolve with income and time. The analysis uses panel data for 133 countries to disentangle the time and income effects in mortality improvement. The data and estimation results confirm that the mortality rates tend to improve with the passage of time or increase in income levels despite the apparently nonlinear degree of improvement. In particular, the mortality rate of young age groups steadily improves over time regardless of income level, whereas that of the elderly accelerates with an increase in income level.

Applying the new mortality rate forecasts and the same birth and immigration rates similar to those in Statistics Korea, this study presents population projections

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[2] In general, the word "risk" is used to describe the situation where we are aware of the probability distribution while "uncertainty" is used in unrestricted situations. Because the word, "longevity risk" is widely accepted and usually refers to risk based on negative bias for life expectancy, I use the word "risk" rather than "uncertainty" in this study.

by age until 2060. Notably, the estimation results for the elderly population differ from those calculated by Statistics Korea in 2011. The number of people aged 65 years and above is estimated to be 21.34 million by 2060, which is 21.2% higher than Statistics Korea's baseline forecast of 17.62 million.

Using these results, this study analyzes the effects of longevity risks on the Korean government's long-term fiscal expenditures, including national pension, basic pension, national health insurance, and national basic livelihood security. Findings indicate that an unexpected spending on the elderly population would increase by 0.1% of GDP in 2020. This percentage will increase to 2.8% by 2060. However, a considerable issue lies on the systematic accumulation of underpredicted errors that worsen the fiscal balance sheets.

In its long-term financial outlook released in December 2015, MOSF (2015) announced that the government debt can be controlled by the 62.4% of GDP by 2060. However, given the longevity risks faced by the Korean government, the 62.4% national debt-to-GDP ratio can hardly be achieved. This goal has been set based on the 2011 population projection from Statistics Korea. However, the accumulation of fiscal spending increases with an unexpected rise in the elderly population from 2015–2060. Thus, the government's debt-to-GDP ratio can be 96.2% by 2060, which is 33.8%p higher than the target level.

The remainder of this paper is organized as follows. Section 2 introduces and analyzes longevity in Korea using life expectancy as the measure. Section 3 discusses a popular mortality prediction model, namely, the LC model and discusses its limitations. In addition, the new mortality forecasting model is proposed in this section. Section 4 presents the population projection results using the new mortality prediction model. Moreover, the economic size of the longevity risk faced by the Korean government in terms of long-term fiscal spending is reported. Section 5 presents the conclusion, along with several policy suggestions.

II. Life Expectancy Increase in Korea

The Organization for Economic Cooperation and Development (OECD) Health Statistics 2015 reports that Korea's life expectancy at birth surged from 52.4 years in 1960 to 82.4 years in 2014, which shows the sharpest rise among OECD member countries. Table 1 reveals that Korea considerably outpaces advanced countries although increasing life expectancy is a worldwide phenomenon.

Mortality rates determine life expectancy. Economic development improves mortality rates among individuals in the following order, namely, children, middle-aged females, middle-aged males, and the elderly. An increase in life expectancy is mainly attributable to a decline in the mortality rate among children during the phase of early economic development, whereas the elderly improves life expectancy as the economy enters a mature phase. Table 2 reveals that this typical pattern can also be observed in Korea. The increase in life expectancy from 1970 to 1985 can be largely explained by improvements in the mortality rates among children and the working age population. However, the post-2000 rise can be attributed to improvements in the mortality rates of the elderly population. In particular, improved mortality rates among the elderly account for 56.3% of the total life expectancy increment during post-2000.

Notably, this pattern can be particularly observed in developed countries such as Japan and the United States. Appendix presents similar tables for Japan (Table A1) and the United States (Table A2). This research finds identical mortality improvement patterns for these countries over a considerably lengthy time horizon.

[Table 1] Increase in Life Expectancy at Birth

Year of Birth	Korea (years)	Japan (years)	US (years)	UK (years)
1960	52.4	67.8	69.9	70.8
2014	82.4	83.7	78.9	81.1
Annual average increase 1960–2014	0.56	0.29	0.17	0.19

Note: Data for 1960 are from the OECD Health Statistics. *2014 Life Table* (Statistics Korea), *Annual Health, Labor and Welfare Report 2015* (Ministry of Health, Labor and Welfare, Japan), *United States Life Tables, 2014* (CDC), National Life Tables: UK (Office for National Statistics, UK) are used for the 2014 data.

[Table 2] Contribution of Mortality Rate Improvement by Age to Increased Life Expectancy: Korea

Period	Increase in life expectancy (annual avg.)	Contribution of mortality rate improvement to increased life expectancy		
		Children (0–14 years)	Working age (15–64 years)	Elderly (65 years and over)
1970–1985	6.64 years (0.44 years)	40.4%	50.3%	9.3%
1985–2000	7.10 years (0.47 years)	24.3%	50.3%	25.3%
2000–2015	6.05 years (0.40 years)	6.9%	36.8%	56.3%

Note: Data are from Statistics Korea (http://kostat.go.kr, access date: 2017. 1. 17). Contribution of mortality rate improvement to increased life expectancy is calculated based on periodic life table by substituting relevant groups' mortalities.

III. Modeling Mortality Improvements

Longevity risks faced by governments can be attributed to the under-forecasting of the elderly population due to an underestimation of mortality improvement. This section analyzes widely used mortality prediction models and introduces alternative models. Subsection 3.1 explains the LC (1992) model, which is the basis for Statistics Korea's population estimates and discusses the model's limitations. Subsection 3.2 introduces a new mortality prediction model. In particular, a non-parametric panel model that determines mortality rate by time and per capita GDP level is explained along with the estimation method.

3.1. Lee–Carter Model

The LC model has been widely adopted across numerous countries, including Korea and Canada. This model is expressed as:

$$\ln(m_{x,t}) = a_x + b_x k_t + \varepsilon_t \,, \tag{1}$$

where $m_{x,t}$ is the central mortality rate for age x at time t. a_x, b_x, and k_t are the parameters of interests. a_x is the average mortality profile by age, k_t tracks changes in mortality over time, and b_x is the rate of mortality change at a given age. a_x is estimated by averaging the log mortality rate over time, while b_x and k_t are calculated by performing a singular value decomposition under normalization restrictions.[3]

The LC model is a simple one-factor model and is a good fit for the linear trend of age-specific mortality improvement. However, a limitation of the model is that the age-specific mortality improvement is constant over time.

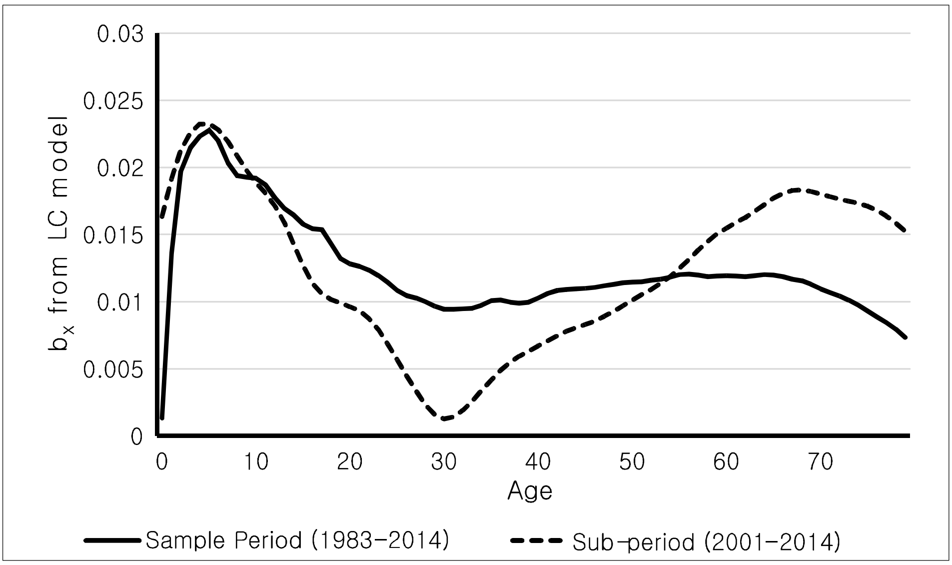
Statistics Korea adopted the LC model for the 2006 population projections and the Li–Lee (LL [2005]) model for the 2011 population projections. The LL model is known to exhibit plausible properties for subgroup mortality forecasting in a given country. In particular, this model maintains gender-based differences in mortality improvement and prevents divergence in mortality in the long run. However, this model fails to solve the fundamental drawback that the mortality improvement pattern is constant over time.

Figure 1 shows the degree of relative mortality improvement among Korean women estimated using the LC model. The estimated values of b_x (solid line) during 1983–2014 and b_x (dashed line) for the subperiod 2001–2014 are presented. Korean women over the age of 60 years have recently shown fast improvement in

[3] Interested readers may refer to Lee and Carter (1992) for general introductions and more detailed discussions.

mortality rate. If the mortality forecasts are based on estimates using data during 1983–2014, then the mortality rate for those aged 10–50 years would be under-forecasted, whereas the rate for those older than 50 years would be over-forecasted.[4] Figure A in the Appendix reports the data for Korean men and indicates that the same conclusion can be drawn for the projections of this population cohort. In particular, the number of elderly would be under-forecasted.

[Figure 1] Estimated b_x in LC Model: Case of Korean Women



These findings validate the under-forecasts for the elderly population. Table 3 summarizes the results of the previous population projections by Statistics Korea. The second column in the table shows the forecasts of the elderly population for 2016–2050. For the same target period, Statistics Korea constantly provided an upward revision that are rather significant. In particular, the revision for the elderly population shows a 15% increase for the past 15 years.[5] These successive revisions are based on the updated elderly mortality data which were under-forecasted in the previous population projections.

[4] Note that estimated b_x represents the mortality improvement speed. Therefore, high level of b_x corresponds to the rapid decrease in mortality.

[5] An elderly group for the target period is defined as those who were older than 51 years in 2001. Note that the revisions are not attributed to changes in birth rates.

[Table 3] Comparison of Elderly Population Projections

Elderly population for 2016–2050		
Source	Sum of elderly population for 35 years (A)	Annual avg. (=A/35)
2001 projection	417,817,916	11,937,655
2006 projection	430,062,386	12,287,497
2011 projection	463,601,732	13,245,764
2016 projection	480,365,535	13,724,730
This work's forecast	504,048,107	14,401,374

Note: The values for "2001 projection," "2006 projection," "2011 projection," and "2016 projection" are from the Population Projection by Statistics Korea at corresponding years. Pop_t^i denotes the population at age i and year t. Thus, the quantity A (the second column) is defined as follows:

$$A = \sum_{t=2016}^{2050} \sum_{i=65}^{100+} Pop_t^i .$$

3.2. New Mortality Forecasting Model: Nonparametric Panel Model

3.2.1. Data

The proposed model requires at least two series, namely, mortality and GDP per capita. This subsection describes the construction of panel data from an individual country's data.

The mortality data are obtained from the United Nations Population Division that generates an abridged life table for 201 countries every five years from 1950–2100. The table provides the central death rate (mx) for the following age intervals, namely, 0–1 year, 1–4 years, 5–9 years, 10–14 years, …, 80–84 years, and older than 85 years. To effectively address each country's heterogeneity, this study creates a mortality index using 2003 as the base year for each country. The GDP and population data by country are taken from Enerdata. GDP per capita is estimated from real GDP in 2005 million US dollars at constant purchasing power parities and using population in thousands. Thus, GDP per capita is expressed in thousands of 2005 US dollars.

This study uses the data of 133 countries from 1973–2013 (five-year frequency). The time span is limited because the GDP data are only available since 1971. In addition, the data exclude 78 countries including most Eastern European countries given that their population data are unavailable for the sample period.

To ameliorate cross-country heterogeneity and generate stable parameter estimates, countries are grouped on the basis of GDP per capita per year. The first group (Gr1) includes the United States and any country with a higher GDP per capita. The empirical distribution of the remaining countries is computed to form the remaining nine income groups (Gr2–Gr10). Subsequently, these countries are assigned to nine income groups according to the grouping rule denoted by percentiles in Table 4. For every group in each year, all countries' GDP per capita is weighed by GDP level as a ratio of the group's total GDP level. Thus, an aggregate measure of GDP per capita for each of the 10 groups are generated for nine years.

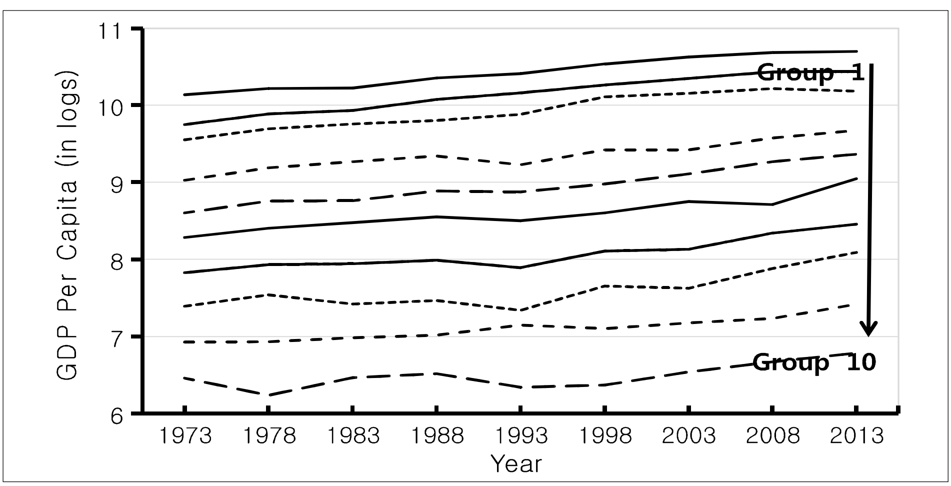
A similar procedure is followed to weight the mortality index data using the GDP-based weights. This procedure yields a total of 90 observations (9 years x 10 country groups) for the mortality index based on the 19 age groups.[6] Thus, the income represented by each group is relatively stable although the group members vary by year. Gr1 is an exception given that it includes the United States that dominates the group because other members are small wealthy countries (e.g., Bermuda and Singapore). Figure 2 illustrates the sample paths for the logs of GDP series.

[Table 4] Income Grouping Rules

Group	Percentiles of GDP per Capita
Gr2	[88,100]
Gr3	[77,88)
Gr4	[66,77)
Gr5	[55,66)
Gr6	[44,55)
Gr7	[33,44)
Gr8	[22,33)
Gr9	[11,22)
Gr10	(0,11)

Note: This rule is the same as *Chang et al. (2016)*.

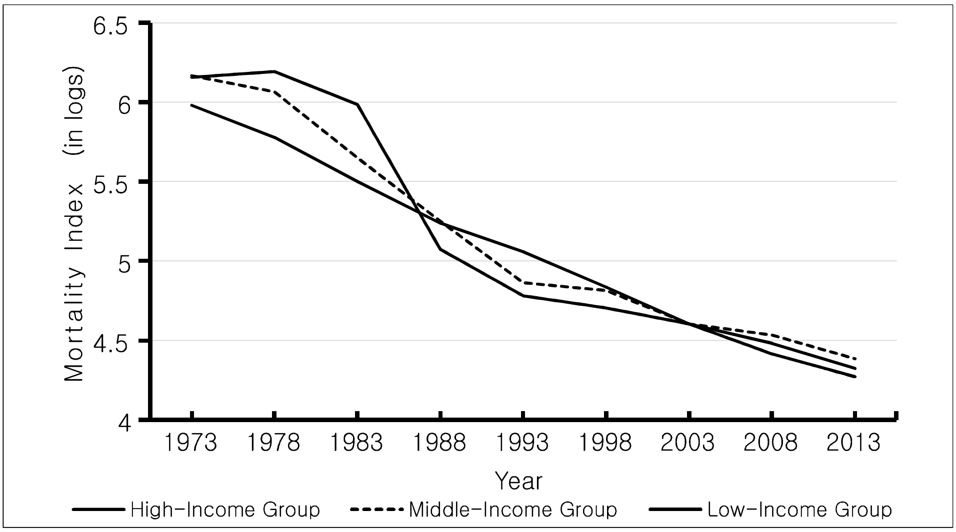
[Figure 2] Time Series Plot: GDP Per Capita by Group



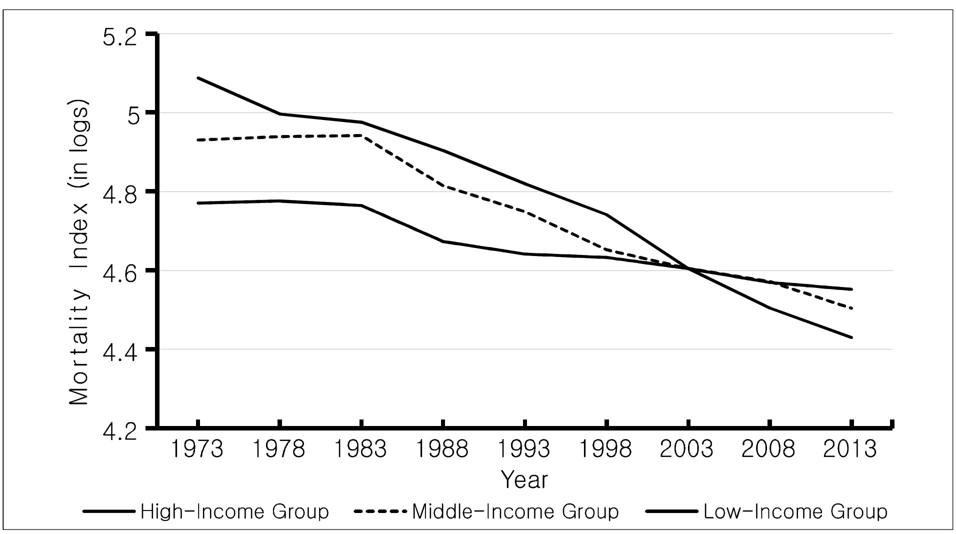
6 The mortality index is constructed for ages 1, 2.5, 7, 12, ..., 72, 77, 82, and 92 years.

Figures 3 and 4 report the male mortality index expressed as the log value of 7 and 82 years. Gr2 (high-income country), Gr5 (middle-income country), and Gr10 (low-income country) are compared to analyze the changing pattern for mortality rate according to income. First, mortality exhibits apparent steady decline among all age and income groups. This finding can be attributed to the development of medical technology over time. However, the effect of income on mortality decline significantly differs by age.

[Figure 3] Time Series Plot: Mortality Index for Boys Aged Seven Years



[Figure 4] Time Series Plot: Mortality Index for Men Aged 82 Years



The most salient feature is the mortality rate for the elderly. Figure 4 reveals that the mortality rate for the elderly in the highest-income countries decreased by 2.7% per year over the past two decades. Since the 1980s, the mortality rate for the elderly has also shown a declining trend in the middle- and low-income countries, and the improvement rate for this age cohort in each country type is 2.2% and 1.1% per year. In particular, the improvement rate in high-income countries is apparently constant for the entire sample period. However, this rate consistently increased only after the 1980s in the middle- and low-income countries.

The second key characteristic is that the mortality rate for the young generation improves the fastest among the low-income group (Figure 3). For example, the mortality rate for seven-year olds in the high-, middle-, and low-income groups improved by 5.5%, 5.9%, and 6.3%, respectively, on the average.

Finally, the mortality improvement rates for all age groups in the high-income group are relatively constant but vary by age. This finding suggests that improvements in mortality can be modeled well as a linear function of time.

The improvement patterns of mortality rate for women are similar to those with men. Figures A2 and A3 in the Appendix exhibit the female mortality index expressed as the log value of 7 and 82 years. The rate of improvement for the old age group is faster in high-income countries (3.4%) than in middle-income (2.5%) and low-income (1.0%) countries. Moreover, the improvement rates for the young age group over the past two decades in low-, middle-, and high-income countries are 6.5%, 6.1%, and 4.9%, respectively.

3.3.2. Non-parametric Panel Model for Mortality

The previous data analysis reveals that mortality rate tends to improve over time, although the speed of improvement varies by GDP level. To demonstrate this observation, this study assumes mortality as a function of income and time and conducts a panel model analysis. Most countries report an increase in income over time. Thus, using data from one country, it is hardly identified whether the improvement pattern is attributable to income or time. This study considers the following non-parametric panel model, which is estimated using the local linear estimator.

For each age group (age = 1, 2.5, 7, 12,…, 72, 77, 82, and 92 years), the following model is applied:

$$\log(y_{t,t}^{age}) = m(x_{i,t}, t) + e_{i,t}, \tag{2}$$

where i and t represent the group based on income and time. $y_{i,t}^{age}$ and $x_{i,t}$ are the mortality index and logged GDP per capita for group i at time t.

The local linear estimators of the regression function m and its derivatives are defined as:

$$\left(\hat{m}(x,r), \widehat{\frac{\partial m}{\partial x}}(x,r), \widehat{\frac{\partial m}{\partial r}}(x,r) \right) = \arg\min_{\alpha,\beta_1,\beta_2} \sum_{i,t} (\log(y_{i,t}^{age}) - \alpha - \beta_1 (x_{i,t} - x) - \beta_2 (t-r))^2 K\left(\frac{x_{i,t} - x}{h_x} \right) K\left(\frac{t-r}{h_r} \right),$$

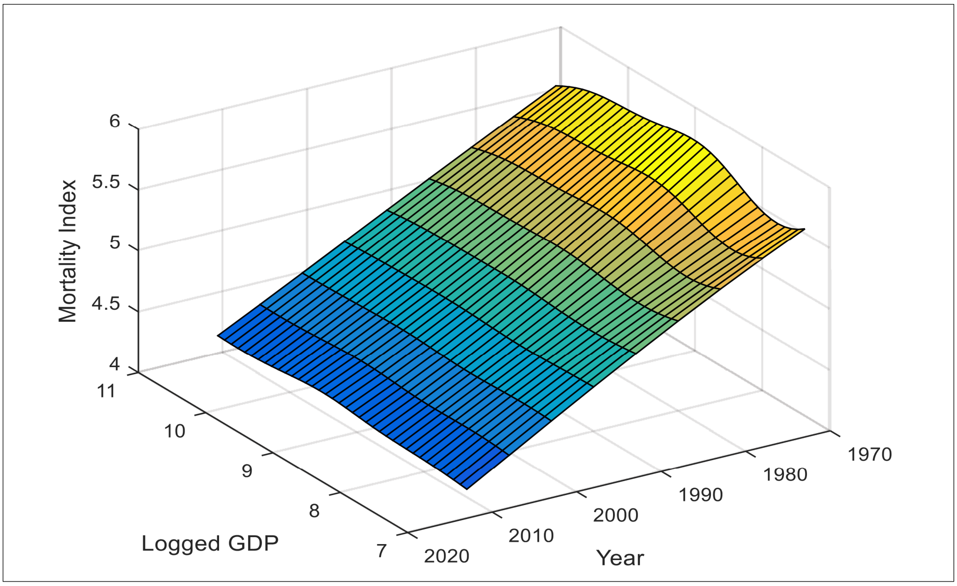
where K is the kernel function, h_x and h_r are bandwidth parameters and $r = 1973, \ldots, 2013$, respectively. For the kernel function K, we use the standard normal density function.

All existing theories for optimal choice of bandwidths h_x and h_r that we use in our estimator are derived under the assumption of stationarity and are inapplicable for our nonstationary models. Nevertheless, we rely on a standard methodology to determine several baseline values of bandwidths that will be modified later. In this study, we employ the procedure on the basis of least squares cross validation. The reader may refer to Li and Racine (2007 p.83–84) for the precise definition of the procedure. As previously discussed, the bandwidth that we obtain from the least squares cross validation is not truly optimal for our model. Given the existence of nonstationarity, a bigger bandwidth than the optimal value under the assumption of stationarity is recommended because nonstationary data are more sparsely distributed than stationary data as shown in the study of Phillips and Park (1998). Readers may also refer to Chang et al. (2016) for detailed discussions on the choice of bandwidth in the presence of nonstationarity.

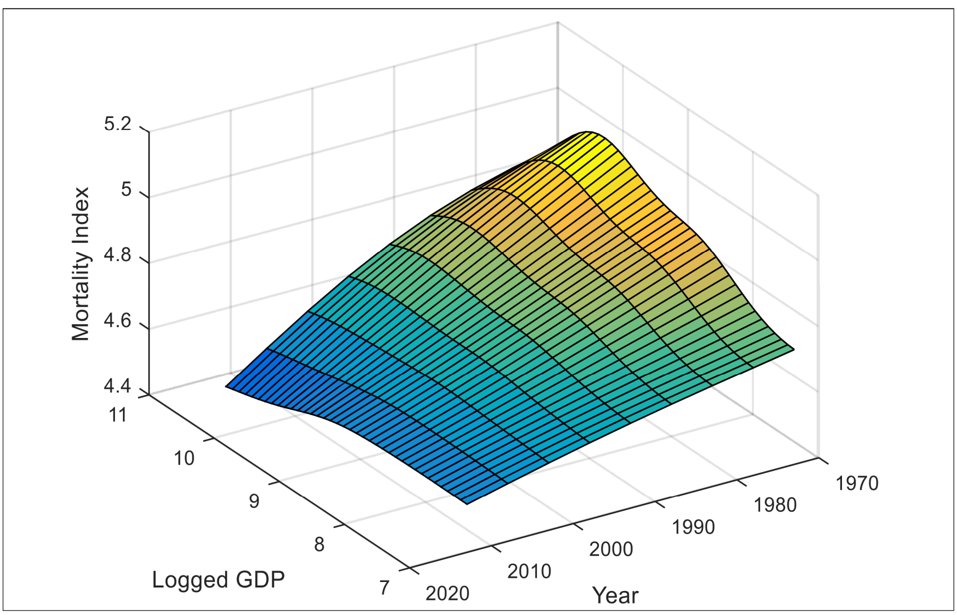
In our analysis, the standard cross validation method generally yields bandwidth values that are approximately 1.5–2 years for h_r and 0.05–0.1 (in logged GDP scale) for h_x. Table A3 shows the selected bandwidths based on the least squares cross validation for each age group. However, we verified that these values are extremely small and produce overly noisy estimates of mortality. Therefore, we use the baseline bandwidths obtained from the application of the least squares cross validation procedure thrice in all our results. The magnification indicates that our observations are non-stationary and sparsely distributed over a wide range of values. Although we do not report the details to save space, we carefully investigated the effects of varying bandwidths as a robustness check and found that all of our discussions and conclusions remain qualitatively valid for a wide range of bandwidth parameter values, including those that we obtain from the application of the standard cross validation procedure. As we decrease the size of the bandwidths, our results simply become noisier.

Figures 5 and 6 present the estimation results of the mortality model for men aged 7–82 years. Both mortality rates improve (decrease) with a rise in time and income.

[Figure 5] Estimation Results for Panel Model: Mortality Index for Boys Aged Seven Years



[Figure 6] Estimation Results for the Panel Model: Mortality Index for Men Aged 82 Years

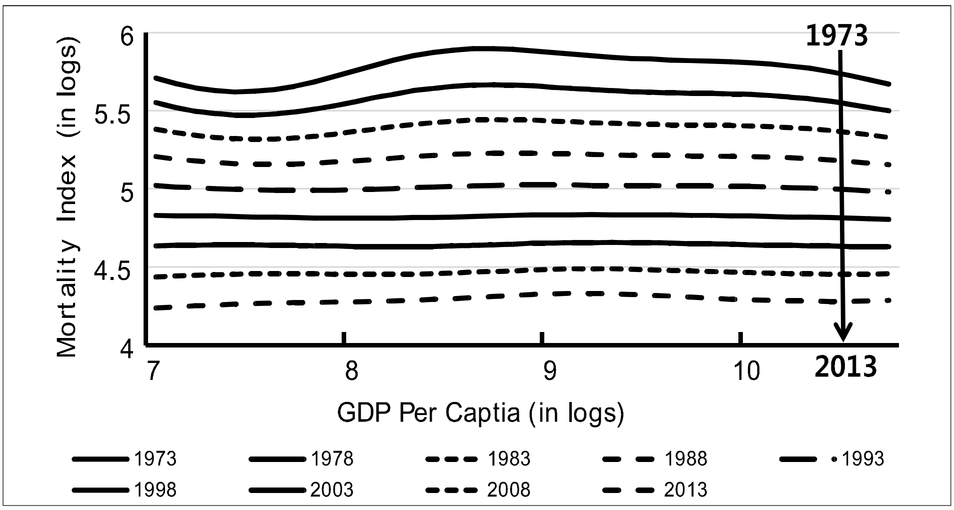


Figures 7–10 are created to further analyze the estimation results. Figures 7 and 8 present the estimation results for $\widehat{m(x_{i,t}, \overline{t})}$, where $\overline{t} = 1973, 1978, \ldots, 2013$ and show the estimation results for the mortality index along with income when time is fixed.

The most notable feature is that all the lines are not staggered and decline with time. Thus, mortality rate improves over time for all income segments. The distance between the lines can be interpreted as the rate of mortality improvement. In particular, a large interval indicates fast improvement rate.

However, the rate of mortality improvement varies by age group and income interval. In the case of seven-year olds, the lines are drawn at even intervals, which signifies that the mortality rate for this age is constant regardless of income level. This type of mortality improvement fits well with and is predicted by the LC model.

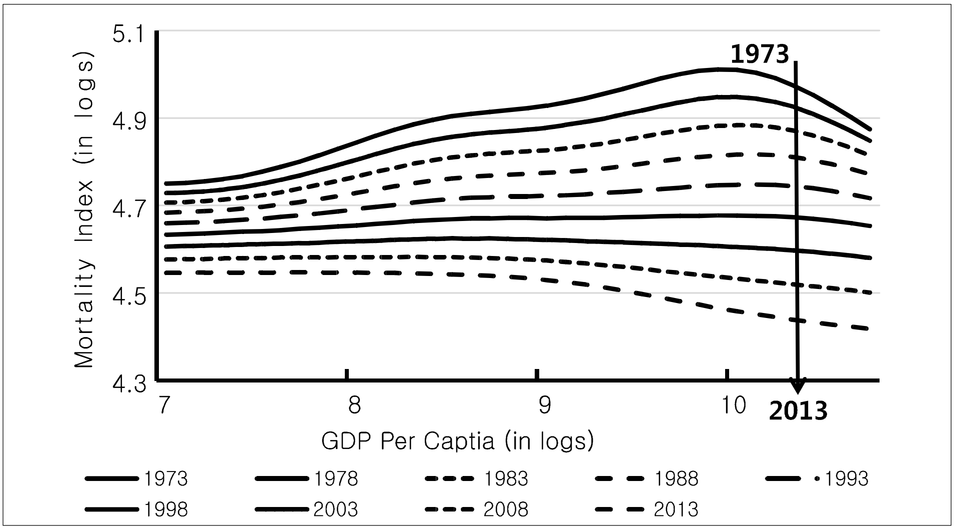
[Figure 7] Estimation Results of Mortality Index for Boys Aged Seven Years with Fixed Year



The characteristics significantly differ for those aged 82 years. In general, the mortality rate is likely to considerably improve with income rise, particularly when the level increases from 5,000 USD (8.5 in logs) to 20,000 USD (9.9 in logs). Furthermore, the mortality rate for the high income segments (i.e., from 30,000 USD [10.3 in logs] to 40,000 USD [10.6 in logs]) recently improved at a faster pace than before. Overall, mortality improvement for the elderly varies by income and time. However, the LC model cannot appropriately demonstrate this feature. Therefore, this study proposes a new mortality forecasting model for Korea, which cannot be suitably represented by the LC-type model given its rapid economic growth.

Such nonlinearity of income level and time-dependent mortality improvement can fit well with a nonparametric model but it is difficult to extend to a prediction model. If we find the stable relationship between mortality rate and the deterministic variable, then we can exploit that relation to build a forecast model.

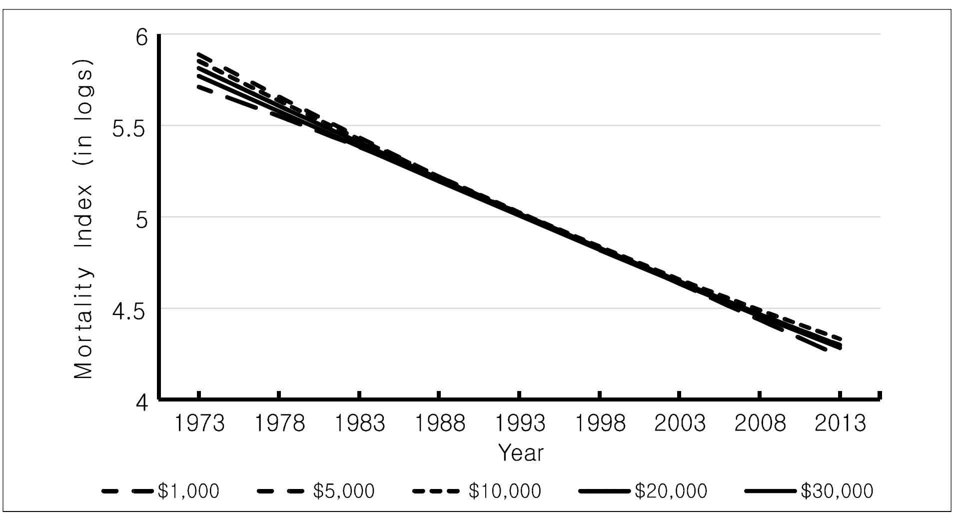
[Figure 8] Estimation Results of Mortality Index for Men Aged 82 Years with Fixed Year



Figures 9 and 10 present the estimation results for the mortality index and time when income level is fixed: $\widehat{m(\bar{x},t)}$, where $\bar{x} = 6.9(\$1{,}000), 8.5(\$5{,}000), 9.2(\$10{,}000), 9.9(\$20{,}000), 10.3(\$30{,}000)$.

The most salient feature of these figures is that the change in mortality is well-estimated as a linear function of time. When the income level is fixed, changes in mortality rate can be modeled as a linear function of time regardless of age. This information is beneficial when attempting to forecast mortality.

[Figure 9] Estimation Results of Mortality Index for Boys Aged Seven Years with Fixed Income Level

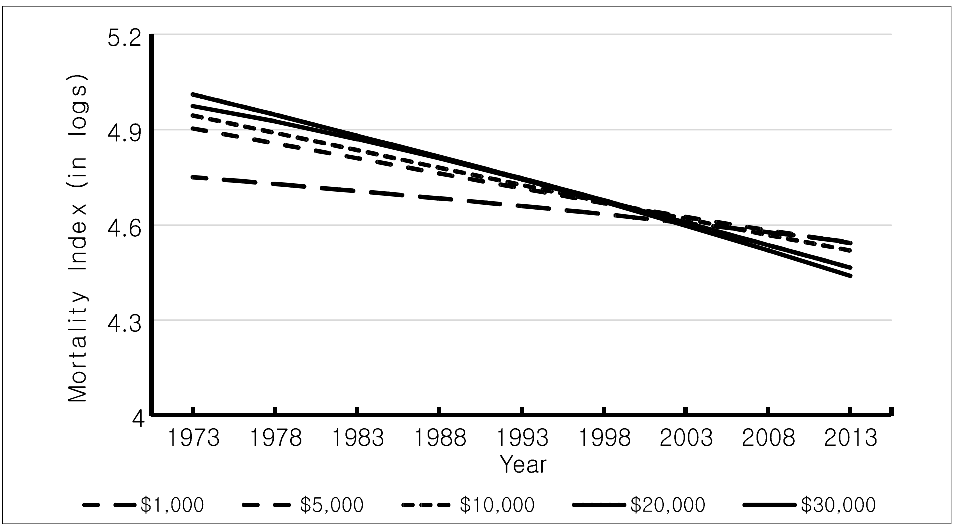


The level of mortality rate widely varies by country, which should be reflected in forecasts. In this study, the individual country factors of mortality change based on gender and age that are estimated and reflected in the forecast as follows:

$$\log(KR_t^{age}) - \log(\widehat{y_{i,t}^{age}}) = \beta(t-2003) + \varepsilon_t\,, \tag{3}$$

where KR_t^{age} is the mortality rate index at time t for a specific age (age = 1, 2.5, 7, 12,…, 77, 82, and 92 years). Note that KR_t^{age} and $y_{i,t}^{age}$ are the same in 2003 given that these are indices that use 2003 as the base year. Table 5 shows the estimation results for Equation (3) in terms of gender and age. The individual country factors for all the age groups are estimated as negative, and the mean value for both genders is −0.021. That is, the improvement in Korea's mortality rate is 2.1% faster than the global average.

[Figure 10] Estimation Results of Mortality Index for Men Aged 82 Years with Fixed Income Level



[Table 5] Estimation Result for Individual Effects: Korea

Age	Men	Women
2.5	−0.04	−0.04
7	−0.041	−0.039
12	0.002	−0.015
17	−0.013	−0.032
22	−0.012	−0.009
27	−0.017	0.004
32	−0.016	0.018
37	−0.028	−0.003

42	−0.033	−0.004
47	−0.031	−0.019
52	−0.024	−0.014
57	−0.014	−0.024
62	−0.034	−0.035
67	−0.028	−0.043
72	−0.02	−0.035
77	−0.013	−0.038
82	−0.006	−0.024
92	−0.005	−0.021
Avg.	−0.021	−0.021

Note: The values in this table are estimates for β in Equation (3).

IV. Evaluation of Longevity Risks for Korean Government

This section summarizes the population projection results using the proposed mortality prediction model. Subsection 4.1 compares this study's population projections for 2060 with those of Statistics Korea. Subsection 4.2 draws on the results in subsection 4.1 to measure the economic size of the longevity risk faced by the Korean government in terms of long-term fiscal spending, including national pension, basic pension, national health insurance, and national basic livelihood security.

4.1. Comparison of Population Projections

The most common method for population projections is the "cohort component" method that accounts for fertility, mortality, and migration. In addition, this method is used by Statistics Korea to project long-term population. This study applies the same assumption for fertility and migration for the purpose of comparison. Table 6 summarizes the population projections using different mortality forecasts. Evidently, the present results significantly differ from those of Statistics Korea. The proposed model reveals that the number of individuals aged 65 years and above will be 21.34 million by 2060, which is 21.1% more than the Statistics Korea's 2011 population projections.

[Table 6] Comparison of Population Projections for 2060

(Unit: Thousands)

Year	Total Population		Elderly population (65 years and above)			
	Statistics Korea (2011)	Proposed model	Statistics Korea (2011)		Proposed model	
				share		share
1990	42,869	42,869	2,195	5.10%	2,195	5.10%
2000	47,008	47,008	3,395	7.20%	3,395	7.20%

2010	49,410	49,410	5,452	11.00%	5,452	11.00%
2015	50,617	50,800	6,624	13.10%	6,640	13.10%
2020	51,435	51,761	8,084	15.70%	8,223	15.90%
2030	52,160	53,018	12,691	24.30%	13,377	25.20%
2040	51,091	52,753	16,501	32.30%	18,050	34.20%
2050	48,121	50,766	17,991	37.40%	20,625	40.60%
2060	43,959	47,586	17,622	40.10%	21,344	44.90%

Note: The values for "Statistics Korea (2011)" are from *Population Projection: 2010–2060* by Statistics Korea (2011).

4.2. Economic Size of Longevity Risks for Korean Government

Statistics Korea's population projection plays an essential role in the government's formulation of new schemes and streamlining of existing policies. In response to the aging population, large-scale social welfare expenditure is expected over the next decades. Therefore, accurate population projections are considered particularly important. For example, in the basic pension system implemented in 2014, expenditure is proportional to the elderly population. That is, an underestimation of the elderly population can weaken fiscal sustainability.

Table 7 presents an estimation of additional fiscal burden attributable to an unexpected increase in the elderly population. Here, the main fiscal expenditure is estimated using 2011 population projections for the elderly by the Statistics Korea and those estimated using the model proposed in this study. To focus on the impact of an unexpected increase in the elderly population, particularly longevity risk, all variables except for population are assigned the same value, and fiscal expenditure is estimated using an identical method.

[Table 7] Estimates for Long-Term Fiscal Expenditure for 2060

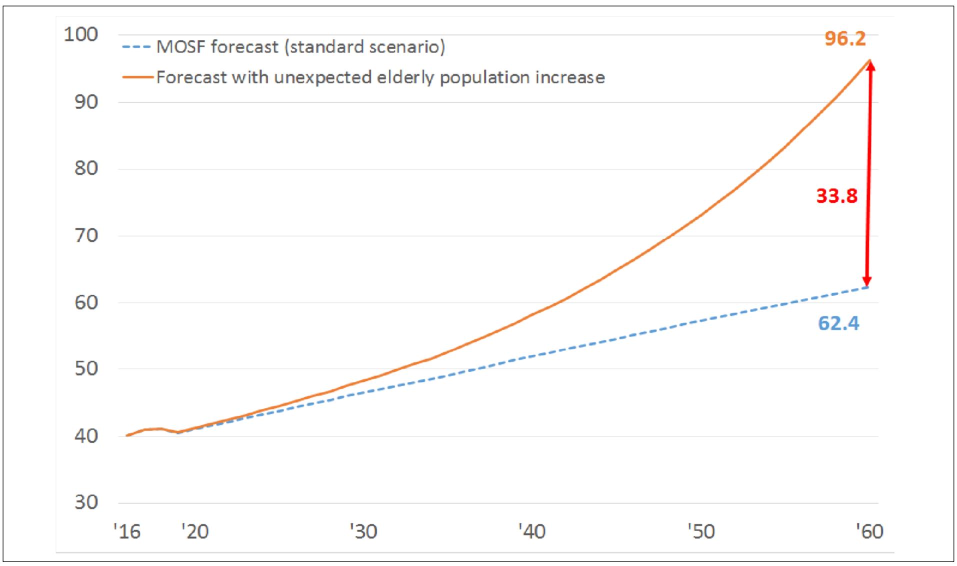
Year	2020			2060		
Fiscal expenditure item	Statistics Korea (2011)	Proposed Model	Gap	Statistics Korea (2011)	Proposed Model	Gap
National Pension	1.6%	1.6%	0.0%	7.3%	8.2%	0.9%
Basic pension	0.8%	0.9%	0.0%	2.6%	3.1%	0.5%
National Health Insurance	0.9%	1.0%	0.0%	2.4%	3.5%	1.2%
National Basic Livelihood Security	0.6%	0.6%	0.0%	0.8%	1.0%	0.1%
Subtotal	4.0%	4.0%	0.1%	13.1%	15.8%	2.8%

Note: The values under "Statistics Korea (2011)" are from *2060 Long-term Public Finance Outlook* by MOSF (2015). Percentages may not appear to add up to the subtotal as a result of rounding up the values.

Results show that the effect of an unexpected increase in the elderly population is merely 0.1% of the GDP in 2020, but this rate increases to 2.8% by 2060. Under-forecasting errors that continue to systematically accumulate and thus deteriorate the fiscal balance sheet is a considerable concern. If these significant longevity exposures are realized in the context of the Korean government, longevity risks can solely increase the debt-to-GDP ratios to 33.8%p by 2060.

Based on MOSF's long-term fiscal projection issued in December 2015, the government will be able to maintain the national debt ratio at 62.4% of GDP in 2060. However, this ration can hardly be achieved with the lack of appropriate measures to address unexpected longevity.

[Figure 11] National Debt Forecast (% of GDP)



V. Conclusions and Policy Implications

Korea experiences an unprecedented rapid increase in life expectancy. This recent increase is mainly attributable to improvements in the mortality rates for the elderly. However, the current mortality forecast model adopted by Statistics Korea fail to appropriately reflect this recent improvement. Thus, its projections for the elderly population is consistently on the lower side. Furthermore, this projection can hinder the government's long-term consolidation efforts and present a serious challenge in formulating and streamlining policies.

This study proposes a new mortality prediction method that shows mortality improvement patterns that evolve with income level and time. The model uses panel data of 133 countries to disentangle the time and income effects in mortality improvement. Then, using the population projections obtained from the new mortality rate forecasts, the model quantitatively measures the economic size of the longevity risk faced by the Korean government. The findings suggest that if significant longevity exposure is realized, longevity risk can solely increase debt-to-GDP ratios by 33.8%p by 2060.

The following limitations should be considered for interpreting the results of this study. First, the economic size of the longevity risk measured in this study crucially depends on the mortality forecasts from the proposed model. However, the forecasts are subject to uncertainty, and the forecasting method has room for improvement including selection of countries, selection method of bandwidth, method of expanding nonparametric estimates, and data handling.

Second, the results of this study are based on the assumption that all other macro variables other than the population would not be changed. We take that assumption to directly analyze the economic effects from an unexpected elderly population increase. However, the increase in population lead to changes in other economic variables.

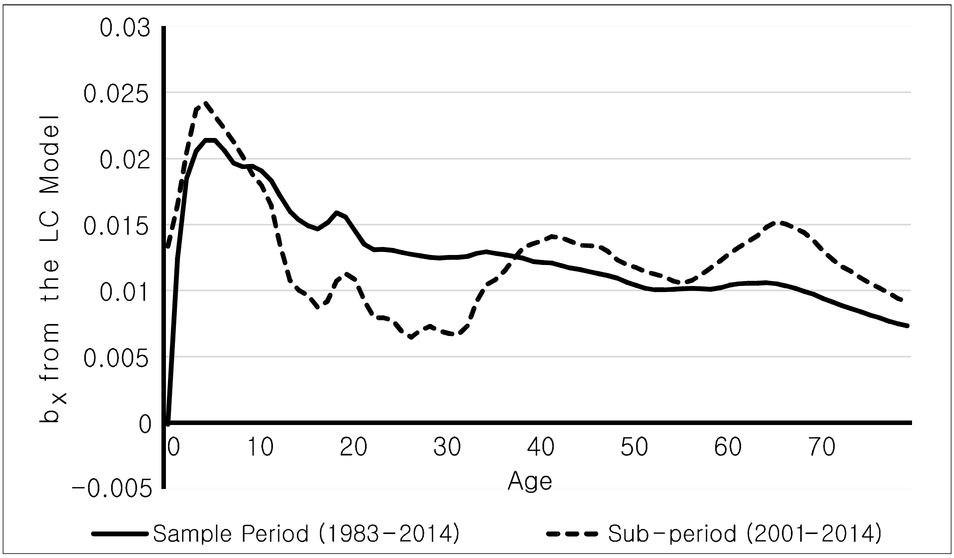
Lastly, we analyzed merely four financial expenditure items in this study. Given that long-term care insurance for the elderly, public employee pension, teacher's pension, and military pension, which are excluded from the analysis, are also affected by longevity risk, the magnitude of longevity risk may increase to a certain degree.

Longevity risk is an undiversifiable and systematic risk that cannot be shouldered by the government alone. To create an environment where all economic agents, namely, the government, businesses, and individuals, can reach a consensus on burden sharing, the government must publicly disclose all the longevity risk information.

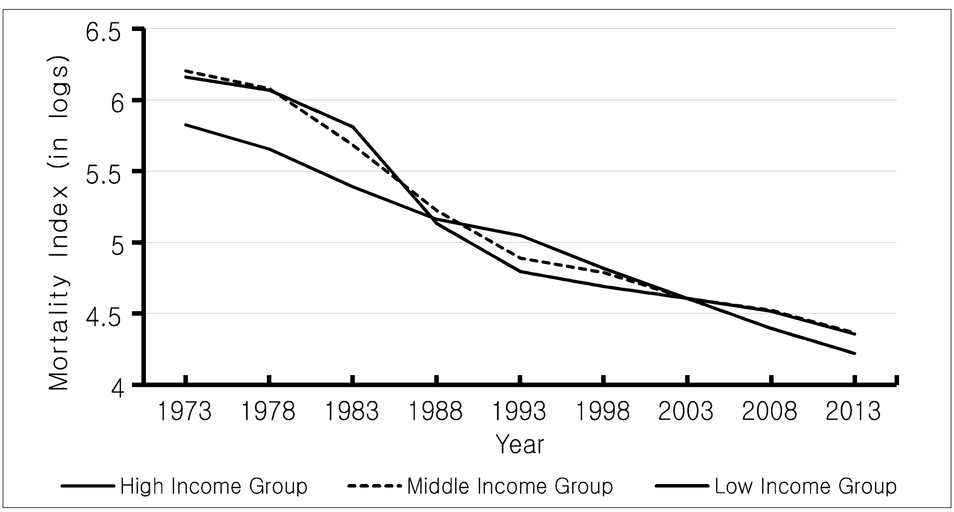
The implementation of a "fiscal automatic stabilizer" as part of a fiscal scheme for various pension and health insurance programs to sustain the balance sheets may also be considered despite the unexpected longevity. The government presently bears the entire burden of longevity risk, thereby implying that the fiscal burden from the current generation is most likely to be passed on to the next. Therefore, Korea should follow countries such as Sweden, Germany, and Japan to introduce a fiscal automatic stabilizer, which is designed to reflect the increasing residual expectation of life in the decremental pension amount. Based on a consensus regarding longevity risks in Korea, this type of pension system reform would be easy to implement and could help mitigate generational conflicts.

Appendix

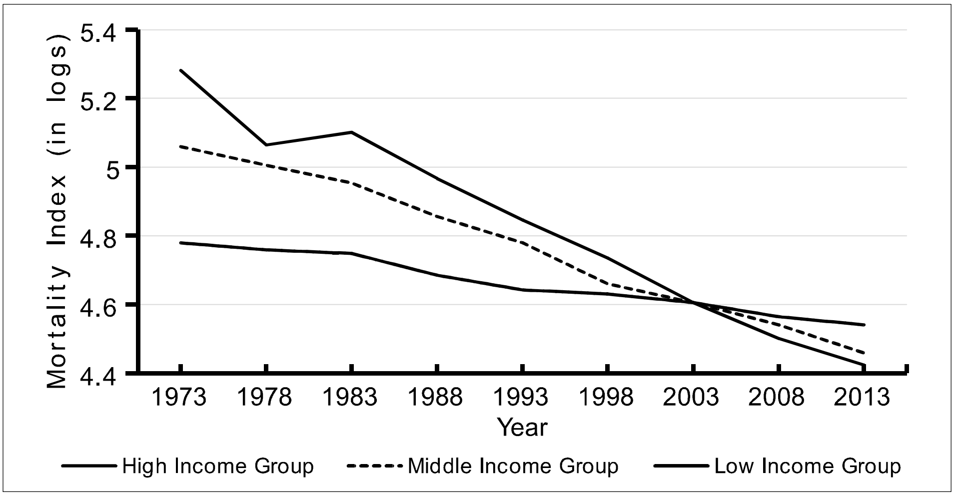
[Figure A1] Estimated b_x in LC Model: Case of Korean Men



[Figure A2] Time Series Plot: Mortality Index for Girls Aged Seven Years



[Figure A3] Time Series Plot: Mortality Index for Women Aged 82 Years



[Table A1] Contribution of Mortality Rate Improvement by Age to Increased Life Expectancy: Japan

Period	Increase in life expectancy (annual avg.)	Contribution of mortality rate improvement to increased life expectancy		
		Children (0–14 years)	Working age (15–64 years)	Elderly (65 years and over)
1949–1971	15.08 years (0.69 years)	43.9%	47.8%	8.3%
1971–1993	6.62 years (0.30 years)	14.6%	33.2%	52.2%
2000–2014	6.38 years (0.46 years)	6.9%	35.4%	57.7%

Note: Data are from Human Mortality Database (http://www.mortality.org, Access date: 2016. 3. 4). Contribution of mortality rate improvement to increased life expectancy is calculated by substituting relevant groups' mortalities based on periodic life table.

[Table A2] Contribution of Mortality Rate Improvement by Age to Increased Life Expectancy: USA

Period	Increase in life expectancy (annual avg.)	Contribution of mortality rate improvement to increased life expectancy		
		Children (0–14 years)	Working age (15–64 years)	Elderly (65 years and over)
1940–1965	7.01 years (0.28 years)	39.7%	42.1%	18.1%
1965–1990	5.16 years (0.21 years)	26.3%	36.3%	37.5%
1990–2015	3.55 years (0.14 years)	12.2%	34.3%	53.5%

Note: Data are from Human Mortality Database (http://www.mortality.org, Access date: 2016. 3. 4). Contribution of mortality rate improvement to increased life expectancy is calculated by substituting relevant groups' mortalities based on periodic life table.

[Table A3] Selected Bandwidths from the Least Squares Cross Validation

Age	Male		Female	
	h_r	h_x	h_r	h_x
0	1.94	0.03	1.97	0.03
2.5	2.14	0.04	2.18	0.04
7	1.70	0.04	1.69	0.05
12	1.71	0.19	1.70	0.17
17	1.68	0.22	1.49	0.05
22	1.82	0.24	1.46	0.05
27	1.97	0.23	1.23	0.04
32	1.21	0.04	1.37	0.05
37	1.21	0.04	1.49	0.05
42	1.25	0.05	1.52	0.05
47	1.40	0.05	1.49	0.05
52	1.46	0.05	1.48	0.05
57	1.60	0.06	1.48	0.05
62	1.40	0.05	1.45	0.05
67	1.34	0.05	1.36	0.05
72	1.40	0.05	1.31	0.05
77	1.63	0.06	1.21	0.05
82	6.42	0.14	1.25	0.05
92	5.87	0.26	1.57	0.06

Note: The values in this table are selected bandwidths (h_r and h_x) by age group and gender based on the least squares cross validation.

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