Mortality, Health, and Marriage:
A Study based on Taiwan’s Population Data

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Summary

The life expectancies have been increasing significantly since the start of 20th century and the trends of mortality improvement are likely to continue in the 21st century. The stochastic mortality models are used frequently to predict the expansion in life expectancy. In addition to gender, age, period, and cohort are three main risk factors considered in constructing the mortality models. Other than these factors, it is believed that the marriage status is related to health and longevity and many studies found that the married have lower mortality rates than those of the unmarried. In this study, we use Taiwan’s marital data of the whole population (married, unmarried, divorced/widowed) to evaluate if the marriage status can be a preferred criteria.

In addition to checking if the mortality rates are the same for different marital status, we want to know if this preferred criteria is valid in the future. We choose two popular mortality models, Lee-Carter and Age-period-cohort models, to model the mortality improvements of various marital statuses. Since the linear dependence in parameters of Age-period-cohort model, we use computer simulation to help us choose appropriate estimation method. Based on the Taiwan marital data, we found that the married have significantly lower mortality rates than the single and, if converting the difference into life insurance policy, the amount of discount is even larger than that of smokers/nonsmokers.

Keywords: Longevity Risk, Mortality Improvement, Age-Period-Cohort Model, Marriage Status, Simulation

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1. Introduction

The prolonging life expectancy has been a common phenomenon in many countries since the turn of 20th century. For example, the life expectancies of the U.S. male and female were both less than 50 years in 1900, and then reached about 74 and 80 years in 2000, respectively. On average, the male and female both gain about 30 years of life over the past 100 years (Figure 1), which is equivalent to gaining about 0.3 years of life annually. The life expectancies in U.S. have been steadily growing and do not show apparent signs of slowing down. The situation in Taiwan is similar since the end of World War II. The life expectancies of male and female also have about 0.2 to 0.3 years of increment annually (Figure 1).

![Figure 1. Life Expectancies in Taiwan and U.S.](image)

The traditional life insurance products are based on the fixed mortality rates, and the prolonging life expectancies would create problems in calculating insurance premiums. For example, if one purchases a deferred life annuity today at age 30 with benefit starting at age 60, there will be at least \(30 \times 0.2 = 6\) years of difference in life expectancy if today's mortality rates are used to compute the insurance premiums. (Assume that the annual increment of life expectancy at age 60 is 0.2 years.) In other words, there is a risk of underestimating insurance premiums for life annuity policies and the insurers may go into insolvency, i.e., longevity risk. Many previous
studies suggest that the mortality risk may cause substantial losses if handled improperly. See, for example, Huang, Yue, and Yang (2008), for a detailed discussion.

In recent years, there are intensive discussions about dealing with the longevity risk. Using the dynamic life table, or equivalently the cohort life table, to replace the traditional life table with fixed mortality rates is one of the possible ways. The search of a reliable mortality model is crucial for implementing the dynamic life table. There are several mortality models and the Lee-Carter (LC) model (Lee and Carter, 1992) probably is the most popular choice. If \( m_{x,t} \) denote the central death rate for a person aged \( x \) at time \( t \), then the LC model assumes that

\[
\ln(m_{x,t}) = \alpha_x + \beta_x \kappa_t + \varepsilon_{x,t}
\]

where parameter \( \alpha_x \) denotes the average age-specific mortality, \( \kappa_t \) represents the general mortality level, and the decline in mortality at age \( x \) is captured by \( \beta_x \). The mortality level \( \kappa_t \) is usually a linear function in time. The term \( \varepsilon_{x,t} \) denotes the deviation of the model from the observed log-central death rates and is assumed to be white noise with 0 mean and relatively small variance (Lee, 2000). The LC model can be treated as a model with the age effect, plus a mixed effect of age and time.

There are several modifications to the LC model, since it was first introduced in 1992. Many modifications consider including extra effects, in addition to the age and age-time effects. For example, Cairns et al. (2009) evaluated 7 modifications of the original LC model, using data from England & Wales and the U.S. Among these modifications, two models (M2 and M8 in Cairns et al.) including “cohort” effect have the best performances. However, unlike in the LC model that Singular Value Decomposition (SVD) is suggested, Cairns et al. did not give suggestions for the estimation of the model parameters.

Adding the cohort effect to the LC model, there will be three effects: age, period, and cohort. Then, this is similar to the Age-Period-Cohort (APC) model in epidemiology. Note that these three effects would produce a linear dependent structure, i.e., Age = Time − Cohort. It has been shown that the estimation process is critical in giving reliable parameter estimates in the APC model. In fact, we found that the estimation process is also crucial in applying the modified LC models (such as M2 and M8).
In addition to age, period, and cohort, there are factors which are believed to be related to human longevity. For example, the smokers generally have higher mortality rates and are charged with higher premiums for life policies than the nonsmokers. Marriage status is another risk factor and many studies showed that the married have lower mortality rates. However, past work of marriage study used sample data and there are doubts about sampling errors. In this study, we will use Taiwan’s marital data, a population data, to evaluate if the marriage status is a feasible choice for preferred criteria.

In addition to checking if the mortality rates are the same for different marital status, we want to know if this preferred criteria is valid in the future. We choose two popular mortality models, Lee-Carter and Age-period-cohort models, to model the mortality improvements of various marital statuses. Since the linear dependence in parameters of Age-period-cohort model, we use computer simulation to help us choose appropriate estimation method. In specific, we shall check if the estimation methods can produce reliable and unbiased estimates for the model parameters.

2. The APC Model

The APC model is used in epidemiology as a preliminary tool in disease incidence and mortality. It provides a mean of descriptive statistics for summarizing the information in a two-way table classified by age group and time period. In general, the APC model includes three effects: age, period, and cohort:

\[ Y_{ij} = \log(R_{ij}) = \log\left(\frac{O_{ij}}{N_{ij}}\right) = \mu + \alpha_i + \beta_j + \gamma_k + \epsilon_{ij} \]  

where \( O_{ij} \) is the number of deaths for the \( i^{th} \) age group (\( i = 1, \ldots, m \)), in the \( j^{th} \) year (\( j = 1, \ldots, n \)), among \( N_{ij} \) persons at risk. It is generally assumed that \( O_{ij} \) follows Poisson distribution. The model parameters \( \alpha_i, \beta_j, \) and \( \gamma_k \) each specify the effects of age, time (period), and cohort, respectively. Note that the cohort effect \( \gamma_k \) satisfies \( k = j - i + m \) & \( k = 1, 2, \ldots, m + n - 1 \). To avoid the problem in computing, it is usually assumed that \( \sum_{i=1}^{m} \alpha_i = \sum_{j=1}^{n} \beta_j = \sum_{k=1}^{m+n-1} \gamma_k = 0 \).
Because the three effects create linear dependency, i.e., determining two effects automatically determining the third effect, there exists identification problem. Several methods have been proposed to solve the identification problem, such as sequential method, autoregressive model, and individual record approach. Robertson et al. (1999) gave a thorough literature review for these methods, and they found that all methods reviewed give acceptable estimates of parameters in the case of nonlinear component. However, Robertson et al. did not consider the variances of the parameter estimates.

Yang, Fu, and Land (2004) introduced a new method for solving the problem of identification. The proposed method is called Intrinsic Estimator (IE) and it uses generalized matrix inverse to acquire unique solution for the parameters. Fu and Cohan (2004) showed the consistency and asymptotic properties of IE, and used simulation and empirical data to demonstrate that IE can yield satisfactory results. The parameter estimates and their variances can be derived via Principal Component regression.

Although the IE is proved having good statistical properties, there are no studies comparing the IE to other solutions of identification problem. In the next section, we will use computer simulation to compare the IE to two other solutions (sequential method and autoregressive model). The simulation results then can be used as a guideline in deriving the estimation method of adding cohort effect to the LC model, such as the LC-cohort model proposed by Renshaw and Haberman (2005).

3. Simulation

We choose two solutions for identification problem, sequential method and autoregressive model, to compare with the IE. The process of applying sequential method is similar to that of the approximation method (Lee and Carter, 1992) for the LC model. The estimation of sequential method can be done in the order of age-period-cohort (apc) or age-cohort-period (acp), according to the importance of the effects. This kind of estimation can be applied to the M2 in Cairns et al. (2007),

$$\ln(m_{x,t}) = \alpha_x + \beta_x \kappa_t + \lambda_x \delta_{t-x} + \epsilon_{x,t}$$  \hspace{1cm} (3)
where the age, period, and cohort effects (i.e., $\alpha_x$, $\kappa_t$, $\delta_{t-x}$) can be estimated using the idea of sequential method.

The period effect $\kappa_t$ in the LC model usually a linear function of time, plus an autoregressive effect. Similarly, the autoregressive model of the APC model assumes that $\gamma_k$ satisfies $\gamma_k = \varphi \gamma_{k-1} + e_k$, with $e_k \sim N(0, \sigma^2)$, still keeping the constraints $\sum_{i=1}^{m} \alpha_i = \sum_{j=1}^{n} \beta_j = 0$. The reason for applying autoregressive relationship to the cohort effect is that the adjacent cohorts are likely to share similar properties and the correlation between these cohorts shall be positive, or $\varphi > 0$.

![Figure 2. Bias of the Parameter Estimates for the APC model](image)

Note: Sacp and Sape are sequential approaches, with a, p, and c indicating age, period, and cohort

There are 10 five-age groups, 5 periods, and 14 cohorts in the simulation. The age effect is a U-shape curve, like the usual mortality curve, the period effect is a (decreasing) linear function of time, and the cohort effect looks like an upside-down U-shape curve. These parameter settings are to mimic the three effects in Taiwan. The simulation is repeated 100 times, assuming that the variance in (2) satisfying $e_y \sim N(0,3)$. Note that computations and simulations in this study were based on an IBM compatible PC.
We shall check the bias and coverage probability to evaluate the sequential method, autoregressive model, and IE. Figure 2 shows the average bias from 100 simulation runs. On average, the autoregressive model and the IE have the best performances, and the age, period, and cohort effects are close to unbiased. The apc sequential method has satisfactory results, but the age effects are slightly over-biased and the cohort effects are under-biased. The acp sequential method is not as good, with the age and cohort effects under-biased and the period effects over-biased. The results of the sequential are similar to those in applying the M2 model, where the order of apc would create more satisfactory results than those of acp.

![Figure 2. Average Bias from 100 Simulation Runs.](image)

![Figure 3. Numbers of Coverage for the APC Model Parameters (100 Runs, 90%).](image)

To see if the estimation methods produce acceptable results, we also use the coverage probability as a check (Figure 3). The confidence coefficient is set to be
Since there are 100 simulation runs, the estimation results are satisfactory if the numbers of coverage are between 84 and 96. In some occasions of age, period, and cohort effects, the ACP sequential method has numbers of coverage smaller than expected. Other three methods have satisfactory results, and apparently, the autoregressive model and the IE have numbers of coverage close to the nominal value. We recommend using these two methods, and only the IE method will be used in the rest of this study.

4. Empirical Study

In addition to the age, it has been recognized that the mortality rates are highly correlated to marriage status. According to Trowbridge (1994), the possible explanations for the married with lower mortality includes selection at marriage, responsibility, living arrangements and reciprocal care-giving, interactions, and social interaction. In recent years, the percentages of married male and female in Taiwan have been decreasing significantly. For example, for the age group of 25-29, the percentages of married female dropped from 90% in 1970’s to 40% in 2000’s. But the overall life expectancies continue to increase every year. It would be interesting to see if the married still have lower mortality rates than those of other marriage status.

The mortality data by marriage status in this study are from the Ministry of the Interior, Taiwan government. There are four groups of marriage status: single, married, divorced, and widowed. Considering the data size, we combine the groups of divorced and widowed into a single group divorced/widowed. Table 1 lists the records of populations and deaths since 1973, the first year that the data are available by marriage status.

Because there are detailed mortality records since 1994, we shall first compare the mortality rates between the periods 1994-96 and 2004-06. We use the results of female as a demonstration (Figure 4). The mortality rates by marriage status in 1994-96 are marked with characters (m: married, s: single, d: divorced/widowed). Apparently, the groups of the married and divorced/widowed have lower mortality rates in all age groups from 1994-96 to 2004-06. The single have lower mortality rates for ages smaller than 50, but have obviously higher rates for female aged 60 to
80. It seems that the mortality improvement does not occur at the older groups of single female in Taiwan.

Table 1. Taiwan Mortality Data by Marriage Status

<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973-1974</td>
<td>15～50+</td>
<td>N/A</td>
</tr>
<tr>
<td>1975-1991</td>
<td>15～50+</td>
<td>15~85+</td>
</tr>
<tr>
<td>1992-1993</td>
<td>15～50+</td>
<td>15~95+</td>
</tr>
<tr>
<td>1994-1997</td>
<td>15～100+</td>
<td>15~95+</td>
</tr>
<tr>
<td>1998-2006</td>
<td>15～100+</td>
<td>15~100+</td>
</tr>
</tbody>
</table>

![Figure 4. Female Mortality Rates by Marriage Status in 1994-96 and 2004-06](image)

To further investigate the differences of mortality improvements by marriage status over 1994-96 and 2004-06, we compute the mortality ratio (Figure 5). The mortality rates of the single are treated as the standard group. The ratios of married vs. single and divorced/widowed vs. single both reduced from 1994-96 to 2004-06, except for younger age groups (ages less than 30). The reduction is especially noticeable for ages over 40 at married vs. single, and for ages over 60 at divorced/widowed vs. single. In 2004-06, the married have the smallest mortality rates for all ages, and the divorced/widowed have almost same mortality rates comparing to the single. In other words, the single have the smallest mortality...
improvement from 1994-96 to 2004-06. A further examination of the mortality rates for the married vs. the single over a longer period (1975-2006, Figure 6) shows similar results, and the married male has larger mortality improvements as well.

Figure 5. Female Mortality Ratio in 1994-96 and 2004-06 by Marriage Status

Figure 7 shows the gains of life expectancies by marriage status, over the 10-year period (1994-96 to 2004-06). The divorced/widowed have the largest increments for the female, and have about the same increments as the married. The single male still have positive gains at the younger age groups, but the single female experience decreases in the life expectancy for all ages. This indicates that the mortality improvements are not homogeneous by marriage status. Both the married and the divorced/widowed show noticeable mortality improvements from 1994-96 to 2004-06.

In addition to the comparison of mortality rates, we also use the APC model to measure the period and cohort effects of mortality improvement by marriage status. As shown in the previous section, the IE is chosen as the estimation method since it has better performances. Also, it requires a certain amount of observations to apply the APC model, and thus the data in the format of 5-age groups (ages 15-49, 7 groups) and 5-year periods (Year 1975-2006, 7 data points) are chosen to guarantee a sufficient data size.
To see the change of a certain age group, we only need to compute the sum of period and cohort effects. Then, the exponential value of this sum is equal to the reduction rate. For example, if the sum is -0.07 for the married, then this means that on average the married would have a reduction of $1 - e^{-0.07} \approx 6.76\%$ in mortality rates for all ages every 5 years. Table 2 lists the averages of period and cohort effects over 1975-2006 for three marital groups. The divorced/widowed have the largest reduction, which are 7.3% and 7.7% every 5 years for the male and female, respectively. The married male and single male have very close reduction rates, which are 2.0% and 2.5%. But the married female have larger reduction rates than the single
female. These results are slightly different than those in Figure 4 (1994-96 vs. 2004-06) because more observations (1975-2006) are used and the estimates of “period+cohort” effects would be different.

Table 2. The Estimate of Period and Cohort Effects by Marriage Status

<table>
<thead>
<tr>
<th></th>
<th>Married</th>
<th>Single</th>
<th>Divorced/Widowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>−0.0196</td>
<td>−0.0251</td>
<td>−0.0762</td>
</tr>
<tr>
<td>Female</td>
<td>−0.0697</td>
<td>−0.0510</td>
<td>−0.0798</td>
</tr>
</tbody>
</table>

5. Applications of Marriage Mortality Rate

The population aging has increased the burden of social insurances in Taiwan. For example, the government raised the premiums for the National Health Insurance and National Pension Insurance in early 2013, and it is likely that the premiums will be raised again in the near future. It seems that the social insurances cannot (and should not) take care all the people’s needs. Unfortunately, about one third of people in Taiwan do not own any insurance policies, and those who have insurance policies are under-insured (Yue and Huang, 2011). To reduce the burden of public finance, Taiwan’s Insurance Bureau, Financial Supervisory Commission, in 2007 started to encourage the life insurance companies to develop preferred status life insurance products, hoping that the premium discount can incur more demands in purchasing insurance products. In practice, although many health insurance policies in Taiwan ask the insured if they are currently smoking, at least 25% of them are not honestly disclosed, according to some insurers (Schwaiger, 2005).

Two risk factors are usually considered in the preferred status insurance, which as smoking and over-weight (obesity). However, these two factors in Taiwan are rarely listed in the health exam form, and the responses of asking if someone is smoking often are doubted by the insurers. Instead, the information if a person is married is easier to collect (i.e., which can be found in the population registration system), and thus the marital status can be used in pricing preferred status insurance. As mentioned in the previous section, Taiwan’s mortality data of marital status are a record of whole population (i.e., census data), and do not have the problem of
selection bias in most sample data. Of course, the mortality rates calculated in the last section require some adjustments before can be used to price insurance products.

The influences of marriage have been studied for a long time, and generally it is believed that the marriage has the role of health protection (Lillard and Panis, 1996; Liu and Umberson, 2008; Henretta, 2007; Manzoli et al., 2007; Williams and Umberson, 2004; Van den Berg and Gupta, 2008) and the married lives longer than the unmarried, or have lower mortality rates (Trude et al., 1994; Cheung, 2000; Gardner and Oswald, 2004; Gove, 1973; Ikeda et al., 2007; Robert and Richard, 2006; Pekka et al., 2005; Michael et al., 2007; Trowbridge, 1984; Yuanreng and Goldman, 1990). Therefore, it seems that using the marital status as the risk factor in the preferred status insurance is a feasible choice.

![Figure 8. Mortality Ratios of Marital and Smoking Status](image)

Figure 8. Mortality Ratios of Marital and Smoking Status

We will first calculate the differences of age specific mortality rates between the married and the single, and compare them with those between the non-smoking and the smoking. Note that the mortality data of smoker status are based on the claim experience of Taiwan insurance companies. We shall use the mortality ratio to check the differences in mortality rates for different marital and smoking status (Figure 8). In general, the married have smaller mortality rates than the single, and the amounts of reductions are about the same as those of the nonsmoking over the smoking. The male apparently benefit more from the marriage and the mortality rates of married
male and are about 40% of those for the single male around ages 30-50. It seems that the marital status is a feasible choice for designing the preferred status insurance, especially for those aged between 30 and 60.

The impact of using the marital status in designing life insurance products can be evaluated by the survival curves. Figure 9 shows the survival curves, staring from age 15, of the single and the married in 2007. The (shadow) areas between survival curves can be treated as the differences of life expectancy between the single and the married, and they match to the results of life expectancy in Figure 10. It seems that the area between the married and the single are larger for the male case, similar to those in Figure 8. Apparently, the advantage of the marriage starts at around age 40, and it quickly accumulates. We expect that the premiums of life insurance products for the married would be significantly lower than those of the single.

We use the whole life insurance to demonstrate the premium differences of using the marital status for the preferred status insurance. The married and single life tables are constructed using the Whittaker graduation, where the exposures of raw mortality rates are based on the assumption of 30/360, or 30 days per month and 360 days per year. The graduation process is to calculate the raw mortality rates of 5-age group first. After graduating 5-age mortality rates, we use the interpolation formula (cubic spline)
and the assumption uniform death distribution to obtain age-specific mortality rates for single age. Note that the mortality rates of people aged 80 and beyond are graduated using the Gompertz law assumption. The estimation of parameters in the Gompertz law used is the weighted least squares (Yue, 2002).

Figure 10. Life Expectancy of Various Marriage Status

The insured ages of whole life insurance considered are from 30 to 60, with payment period of 20 years, and the interest rate is 2% or 5%. Tables 3 and 4 are the annual pure premiums for coverage amount of per $1,000. As expected, the married male have a larger discount in premiums and the discount is about 40% and 35% for 5% and 2% interest rate, respectively. Other than comparing the married with the single, we also compare the married with the whole population, where the population data are from Human Mortality Database. The reason for comparing with the whole population is to avoid marriage discrimination. In other words, we shall treat all insured equivalently and only give discounts to those are married. Given 5% of interest rate, the premium discounts for the married vs. the whole population are about 7%~16% and 6%~8% for the male and female, respectively. The discounts in the case of 2% interest are smaller.
### Table 3. Premiums of 20-year-pay Whole Life (Interest Rate: 5%)

| Age | Male         | Female           |            |            |            |            |            |            |            |
|-----|--------------|------------------|------------|------------|------------|------------|------------|------------|
|     | Married      | Single           | Married/   | Married/   | Married    | Single      | Married    | Single      | Married/   | Married/   |
|     |              |                  | Single     | HMD        |            | HMD        |            |            | HMD        | HMD        |
| 30  | 23.13        | 37.06             | 0.62       | 0.84       | 15.52      | 19.17      | 0.81       | 0.92       | 15.52      | 19.17      |
| 35  | 28.78        | 48.19             | 0.60       | 0.86       | 19.40      | 23.54      | 0.82       | 0.93       | 19.40      | 23.54      |
| 40  | 35.48        | 61.12             | 0.58       | 0.88       | 24.24      | 28.64      | 0.85       | 0.94       | 24.24      | 28.64      |
| 45  | 43.83        | 75.70             | 0.58       | 0.90       | 30.21      | 35.00      | 0.86       | 0.94       | 30.21      | 35.00      |
| 50  | 55.18        | 93.68             | 0.59       | 0.91       | 37.90      | 43.52      | 0.87       | 0.94       | 37.90      | 43.52      |
| 55  | 71.31        | 116.99            | 0.61       | 0.93       | 48.57      | 55.10      | 0.88       | 0.93       | 48.57      | 55.10      |
| 60  | 94.11        | 151.31            | 0.62       | 0.93       | 64.01      | 74.34      | 0.86       | 0.92       | 64.01      | 74.34      |

### Table 4. Premiums of 20-year-pay Whole Life (Interest Rate: 2%)

| Age | Male         | Female           |            |            |            |            |            |            |            |
|-----|--------------|------------------|------------|------------|------------|------------|------------|------------|
|     | Married      | Single           | Married/   | Married/   | Married    | Single      | Married    | Single      | Married/   | Married/   |
|     |              |                  | Single     | HMD        |            | HMD        |            |            | HMD        | HMD        |
| 30  | 37.28        | 49.36             | 0.76       | 0.91       | 30.60      | 33.81      | 0.91       | 0.96       | 30.60      | 33.81      |
| 35  | 42.14        | 59.25             | 0.71       | 0.91       | 34.10      | 37.67      | 0.91       | 0.96       | 34.10      | 37.67      |
| 40  | 47.89        | 70.99             | 0.67       | 0.91       | 38.28      | 42.05      | 0.91       | 0.96       | 38.28      | 42.05      |
| 45  | 55.23        | 84.65             | 0.65       | 0.92       | 43.35      | 47.43      | 0.91       | 0.96       | 43.35      | 47.43      |
| 50  | 65.53        | 102.04            | 0.64       | 0.93       | 49.96      | 54.84      | 0.91       | 0.96       | 49.96      | 54.84      |
| 55  | 80.76        | 125.34            | 0.64       | 0.94       | 59.48      | 65.56      | 0.91       | 0.95       | 59.48      | 65.56      |
| 60  | 103.03       | 159.90            | 0.64       | 0.93       | 73.93      | 84.03      | 0.88       | 0.93       | 73.93      | 84.03      |

### 6. Discussions and Conclusion

Mortality Improvement is a common phenomenon in many countries and people are expected to live longer. Prolonging life expectancy puts the insurers into a higher risk of insolvency if the longevity risk is underestimated. Because the rapid population aging and the growing need of life annuity products, the insurance industry needs to figure out solutions for dealing with this risk. The dynamic life table (or cohort life table) is one of the possible solutions, and most of them rely on mortality models. The Lee-Carter Model probably is the most popular mortality model and several modifications of the LC model have been proposed. Among all modifications, introducing the “cohort” effect into the model is a common variation of the LC model.
in addition to the age and period effects. However, because the three effects would create linear dependency, the estimation of three effects needs to be careful.

Other than the LC model, the age-period-cohort (APC) model has been a frequently used tool in epidemiology and many solutions are proposed to deal with the problem of linear dependency. In this study, we use computer simulation to evaluate three estimation methods for the APC model, including a recently proposed method (IE). Judging from the bias and coverage probability, we found that the IE is a feasible method; in addition to that the estimates and their variances can be derived directly. The autoregressive model can be treated as an alternative method for the parameter estimation. We suggest using the approaches of IE and autoregressive models to deal with the problem of linear dependency, when the cohort effect is introduced in the LC model.

The empirical study of Taiwan mortality by marriage status suggests that the divorced/widowed have the largest gains in the life expectancy. The married can benefit from the marriage and their mortality rates at all age groups also have declined significantly. On the other hand, the single have the smallest mortality improvement among three marriage status, and the single elderly even experienced an increase in mortality rates. Applying the mortality data by marriage status to the APC model, the results are similar and the divorced/widowed have the largest mortality reductions, but the differences between the married male and single male are smaller. The results of applying the Lee-Carter model are similar and are omitted here.

The married male would receive about 24%-42% discount in pure premium than the single male. It seems that married or not can be regarded as mortality risk factor for male. The advantage on the research is we use the complete population record data in Taiwan to analysis the relationship of marriage status and mortality. We have the same results as scholars in many countries did. Hence we suggest the future social security disbursement should also take marriage forecast into consideration and provide insurance companies some references in designing life insurance products. It also indirectly encourages marriage motivation to increase fertility rate.

Further, we use the computer simulation evaluate the estimation methods of the APC model. The goal is to study the estimation methods and provide possible suggestions for the LC model, if the cohort effect is to be introduced into the mortality model. We found that the IE and autoregressive models outperform the sequential approach in the parameter estimation of APC model. Since adding the cohort effect in
the Lee-Carter model usually adapts approach similar to the sequential APC model (Renshaw and Haberman, 2005; Cairns et al., 2009), there may be rooms for improving the estimation. Of course, we do not intend to mean that the APC model is a better model, or adding the cohort effect is the only way to modify the LC model. For example, Debón et al. (2008) proposed a geostatistical modification to the LC model, adding a spatial autocorrelation to the residuals of LC model.
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