Research Paper

# CIA2014: A Mortality Table Constructed from the CIA Individual Insurance Data of Policy Years 2009–2019

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# 1 Abstract

This paper documents the construction of a new mortality table using the data of the last 10 years of experience of the Canadian Institute of Actuaries (CIA) individual insurance mortality study. The table constructed is named CIA2014 and is adjusted with improvement to be applicable to January 1, 2014. The select period is 20 years. There are separate tables for males and females, smoker, non-smoker, smoking unknown (ultimate only), and all combined, and for age nearest and age last; there are 16 tables, 12 of which are both select and ultimate. The construction method for the majority of the tables is Whittaker–Henderson in two dimensions. The paper also proposes two alternatives for dealing with the fact that mortality tends to decrease substantially with the increasing size of the policy and that the distribution by size is not consistent across ages and durations.

The mortality rates for CIA2014 are available on the CIA website in a traditional format and in AXIS format.

In June 2022 it was determined that there were incorrect numbers in Table 1 and Table 6 of the report published in April 2022. The error involved the calculation of expected claims for non-smokers in CIA9704. Those tables have been corrected in this version. None of the numbers of CIA2014, or of any calculations in this report using CIA2014, were in error.

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# 3 Background

## 3.1 Terminology

"Year" can be used with a variety of meanings. The use of "year" in this report is clarified here.

"Calendar year" (or simply a four-digit year) refers to the whole designated year. For example, "calendar year 2014" or "2014" refer to January 1, 2014, to December 31, 2014.

"Policy year(s)" (followed by two four-digit years) refers to the period of experience beginning with the policy anniversary in the first-mentioned calendar year and continuing to the day before the anniversary in the second-mentioned calendar year. This can refer to the experience of a single policy, but more commonly refers to the experience of a group of policies. For example, "policy years 2009–2019" refers to the 10-year period beginning with the anniversary in 2009 and ending the day before the anniversary in 2019.

"Policy year *n*" or the "*n*-th policy year" refers to the year beginning *n*-1 years after issue and continuing to the day before the *n*-th policy anniversary. For example, the second policy year for a policy issued on February 14, 2014, runs from February 14, 2015, to February 13, 2016, inclusive.

"Duration" in this report always refers to the exact time in years from issue date to the date under consideration; it may be fractional. To avoid confusion, duration 1 is never used to be synonymous with policy year 1, which runs from duration 0 to the day before duration 1.

"Age" is always age nearest birthday, and may be used as issue age or attained age.

"$q_{[x]+t}$" is the probability that a life age $x$ at issue and at exact duration $t$ will die within one year. This is also referred to as the mortality rate for issue age $x$ and policy year $t$+1.

"Risk class" refers to the various combinations of sex and smoking classifications, and eight are distinguished in this report. "Msm" stands for male smokers, "Fsm" for female smokers, "Mns" for male non-smokers, "Fns" for female non-smokers, "Munk" for male with smoking unknown, "Funk" for females with smoking unknown, "Mall" for male with all smoking classes, and “Fall” for female with all smoking classes. When all risk classes are shown, they appear in this order.

“Deaths” refer to the number or more commonly the face amount of policies terminating by death. The amount of a death claim may not be the same as the face amount in the case of many universal life policies and in the case that a claim for benefits is settled at some lesser amount.

## 3.2 Earlier tables

Several tables have been developed by the Canadian Institute of Actuaries (CIA) using data from its life insurance mortality studies. Some of them are C.A. 1958–64 (a five-year select table), C.A. 1969–75 (the first 15-year select table), CIA8288 (the first with separate rates for smokers and non-smokers), CIA8692, and CIA9704. No new life insurance table has been published since CIA9704 in 2010.

## 3.3 Need for a new table

The most recent CIA individual life mortality study concluded that there is a need for a new table because neither CIA8692 nor CIA9704 have a slope by age or duration that fits well with recent experience. Therefore, the table cannot be adjusted by a simple multiple. A new table is the only practical solution.

Table 1 shows the actual-to-expected (A/E) ratios by amount with expected on CIA9704 with projection on MI-2017 from the assumed base year of 2001 to the middle[1] of the calendar year in which the policy year starts.

[1] Experience is by policy year. For example, consider the policy year 2018–2019. On average, the policy year runs from the middle of 2018 to the middle of 2019. The raw mortality rates obtained from the data are estimates for the probabilities of death in the year following the middle of 2018. Therefore, one must apply 17.5 years of improvement. One uses a full year of improvement for each of 2002–2018 and half a year of improvement on the factor for 2019 to obtain a mortality rate that would be appropriate for “expected.” In this way, the actual mortality and the expected mortality are for the same one-year period. See the Appendix for a numerical example.

The smoking combined version of CIA9704 is used for expected for both smoking unknown and for all combined. The smoking-distinct versions are used for smoker and non-smoker.

**Table 1. Actual-to-expected ratios on CIA9704 with MI-2017 by amount for policy years 2009–2019**

| Pol Year | Msm | Fsm | Mns | Fns | Munk | Funk | Mall | Fall |
|---|---|---|---|---|---|---|---|---|
| 1–5 | 81.6% | 76.3% | 84.2% | 71.6% | 103.0% | 88.6% | 80.4% | 71.9% |
| 6–10 | 79.5% | 76.6% | 85.8% | 75.7% | 89.4% | 71.4% | 77.3% | 69.5% |
| 11–15 | 85.6% | 101.7% | 83.5% | 79.3% | 88.9% | 76.4% | 71.9% | 68.4% |
| Ult | 101.0% | 121.3% | 92.1% | 90.0% | 107.9% | 104.3% | 89.3% | 83.8% |
| All | 92.5% | 105.4% | 88.7% | 82.9% | 107.5% | 102.9% | 84.6% | 77.8% |

## 3.4 CIA annual mortality study

The CIA has for 70 years conducted an annual intercompany mortality study on the experience under individual life insurance policies with normal underwriting at issue. This study has been important to establish a benchmark for industry experience.

The work on the new table is based on the seriatim records for the annual mortality studies of the last 10 years, policy years 2009–2019. As with the published study, policies issued due to conversion, guaranteed insurability, or with a substandard rating are excluded; simplified and guaranteed issue policies and joint policies are also excluded. Having access to the seriatim records was desirable to explore anomalies in the data and to make adjustments (described below) to lessen the impact of fluctuation from very large policies. In large measure, the work could have been accomplished using the annual databases provided by the CIA.

Table 2 summarizes the data that has been selected.

| Table 2. Totals of data obtained from Individual Life Mortality Study for policy years 2009–2019 (amounts in thousands) | | | | |
|---|---|---|---|---|
| | **Exposure** | | **Deaths** | |
| | **Count** | **Amount** | **Count** | **Amount** |
| Msm | 6,623,688 | 857,072,274 | 50,351 | 2,830,538 |
| Fsm | 5,847,673 | 497,557,877 | 39,412 | 1,479,269 |
| Mns | 26,074,051 | 7,135,295,634 | 112,215 | 12,985,807 |
| Fns | 25,670,952 | 5,005,325,427 | 85,776 | 6,002,330 |
| Munk | 14,594,120 | 527,365,292 | 257,286 | 3,891,114 |
| Funk | 10,983,657 | 403,937,463 | 129,994 | 1,082,560 |
| Mall | 47,291,858 | 8,519,733,199 | 419,851 | 19,707,459 |
| Fall | 42,502,282 | 5,906,820,767 | 255,182 | 8,564,160 |
| All | 89,794,140 | 14,426,553,966 | 675,033 | 28,271,619 |

Note that all data is either submitted as or converted to age nearest birthday. Unless otherwise stated, all measures of age are on age nearest birthday.

In keeping with the tradition of insurance mortality tables in Canada, the experience used in construction is by amount, not by count. Using data by amount is appropriate because it is expected that the resulting table will be used primarily for financial calculations.

## 3.5 Modifications to data

Although the data, as summarized in Table 2, could be used for table construction, there are some modifications that will yield a better base for the new mortality table.

### 3.5.1 Renewable term

Most renewable term policies sold in recent years have a significantly higher[2] premium rate at renewal than for a new term policy at the same attained age. It is expected that most

[2] There are some renewable term products, not commonly sold now, which had a premium rate at renewal the same as for a new issue at that age. These products would be much less likely to exhibit

who can qualify for standard insurance at renewal will purchase a new policy. Accordingly, the mortality experience after the first renewal will be heavier than normal. For this reason, it is not appropriate to include the experience after the first renewal in the data used to construct the mortality table.

Experience after the first renewal has not been excluded from tables in the past because the data available then did not allow for that exclusion to be made. The codes for product type were expanded for the 2011–2012 policy year to allow the exclusion to be made. For the two earlier policy years, the exclusion was made approximately based on the distribution of term length in each company as shown in 2011–2012.

### 3.5.2 Anomalies

A search for records that appear briefly in the study and then disappear yielded three large cases. Two appear in the policy year 2009–2010. Both of these do not appear in the CIA data until the year of death. One is for Mns, issue age 69, policy year 15, with $6 million of insurance. The other is for Munk, attained age 92 in the ultimate for $2.2 million. On further investigation, no explanation could be found for the first; the second was found in earlier years but for an incorrect lesser amount. The first case was deleted, and the second was retained with the earlier records corrected.

The third case is for Fsm, issue age 79, policy years seven and eight, with $2.5 million of insurance in the two policy years 2014–2016. Death occurred in the second of those years. There being no explanation for the case not appearing prior to 2014–2015, these two records were deleted.

### 3.5.3 Fluctuations from large policies

The presence or even absence of very large claims can have a large effect on the observed mortality rates. Some have omitted very large policies or put a cap on the amount of insurance for any one record. The result from both approaches is to exclude some valid

higher mortality after renewal, but there is no practical way to include these types of renewable term and exclude others after the first renewal.

exposure and claims. The choice for this task is to include all policies, but if the face amount be $1 million or more, the actual face amount is replaced[3] by $1.5 million.

### 3.5.4 Adjustment for mortality improvement

Mortality improvement is a fact of life in Canada. Although there are fluctuations at various times and ages, the general trend of mortality is downward and has been for many years. It seems reasonable and desirable to reflect mortality improvement in the construction of a mortality table. All recent annuitant tables have been adjusted for mortality improvement, but life insurance tables of the CIA have not been, until now.

What improvement scale should be used? The obvious choice is the one most recently developed, MI-2017. There is currently a research project underway to develop a new improvement scale; it may be better to use that new scale. However, waiting would delay this project for a year or even more. Therefore, MI-2017 is used.

How is the adjustment to be made? Typically, an improvement scale is applied to mortality rates. In this case, because the rates are to be determined, it would be computationally difficult to adjust the mortality rates. Fortunately, there is a simpler approach which can be shown to be equivalent. The adjustment for improvement is applied to the death claims. That is, the actual death claims of each year of experience are divided by a factor which would have been used to adjust a mortality rate from the base year to the year of experience. The result is that the adjusted amount of deaths claims is consistent with what would theoretically have been experienced in the chosen base year.

[3] The modification was made at the level of record, but the assignment to size band could span several records. The size band was determined by sum of the amounts of records with the same policy number, issue date, birthdate, and sex. The actual average size of records assigned to bands of $1 million or higher for the 10-year period was $1,477,739. If one used the published databases and divided the total amount exposure by the total policy count exposure, one would get $1,619,513, but that “average” is not the same thing because riders count in the numerator but not in the denominator. Dealing with policy counts is complicated because there is no clear definition of “policy” for actuarial purposes. Incidentally, after changing all amounts of $1 million or more to $1.5 million, exposed amount divided by exposed policy count increases slightly, to $1,637,816.

But will that adjustment not make the new table dependent on MI-2017[4] and obsolete if the new improvement scale is markedly different? There is a risk that that would be true, but the risk is very substantially mitigated if the base year is central to the experience used in construction. Then approximately half of the claims are brought forward (decreased in size to reflect future mortality improvement) and half are brought backward (increased in size to reflect past mortality improvement). A test using Scale AA instead of MI-2017 resulted in mortality rates that were very close to those of CIA2014.

What is the average time that the policy years start? Table 3 shows the average year, weighted by amount, for the 10 policy years 2009–2019, calculated as follows. By assuming a uniform distribution of issues through the year, we conclude that each policy year represents experience that, on average, runs from the middle of one year to the middle of the next. For example, the experience of the policy year 2018–2019 is represent by 2018.5 in the calculation, that being the average time that the policy year starts. The average is calculated by weighting by the amount exposed in each policy year for the respective ages.

[4] A test using Scale AA rather than MI-2017 yields mortality rates that differ from CIA2014 by 0.3%. Because Scale AA is very different from MI-2017, this differential was judged small enough that dependency on MI-2017 is not an issue.

| Table 3. Exposure (in millions) and average time for start of policy year | | |
|---|---|---|
| **Attd Age** | **Exposure** | **Avg Year** |
| 0–9 | 196,270 | 2014.67 |
| 10–19 | 305,527 | 2014.29 |
| 20–29 | 938,011 | 2014.28 |
| 30–39 | 3,226,708 | 2014.38 |
| 40–49 | 4,241,375 | 2014.35 |
| 50–59 | 3,081,181 | 2014.46 |
| 60–69 | 1,210,012 | 2014.64 |
| 70–79 | 341,003 | 2014.72 |
| 80–89 | 111,865 | 2014.62 |
| 90+ | 14,511 | 2015.31 |
| All | 13,666,463 | 2014.42 |

The average year varies significantly by age group. Overall, the weighted[5] average start of policy years is 2014.42, which represents June 2, 2014. To be consistent with the construction of the improvement scale, it is preferable to have a mortality table based on January 1[6] of a year. Accordingly, the base of the table is taken as January 1, 2014, requiring a net adjustment of under half a year. The table is named CIA2014.

[5] The unweighted average would be 2014.0, but the weighted average is later because the amount of exposure has increased through the 10-year period.

[6] See the example and formulas for applying improvement factors of CPM-B in CIA publication 214013, p. 9. The same approach was used with MI-2017 (publication 217097, p. 10).

Note that by the adjustment for mortality improvement, the amount of death claims is decreased for the earlier years to reflect assumed improvement to 2014, and the amount for later years is increased to remove assumed improvement since 2014.

### 3.5.5 Data used for CIA2014

Table 4 is like Table 2 but after all the modifications mentioned above were made. The data used in constructing CIA2014 is the data summarized in Table 4 and referred to as the "modified" data. Unless explicitly stated to the contrary, the modified data is used in the tables below in this report. The alternate set of data, referred to as the "original" data, is the data shown in Table 2 excluding the experience of renewable term after the first renewal.

**Table 4. Totals for data to be used in constructing CIA2014. Includes policy years 2009–2019 (amounts in thousands)**

| | Exposure | | Deaths | |
|---|---|---|---|---|
| | Count | Amount | Count | Amount |
| Msm | 6,233,179 | 800,424,117 | 47,391 | 2,481,434 |
| Fsm | 5,554,533 | 459,530,328 | 37,994 | 1,305,916 |
| Mns | 24,402,354 | 6,706,589,498 | 106,564 | 11,546,272 |
| Fns | 24,241,036 | 4,839,198,774 | 82,982 | 5,554,014 |
| Munk | 14,393,511 | 512,810,344 | 255,262 | 3,854,550 |
| Funk | 10,824,320 | 389,782,712 | 129,332 | 1,072,352 |
| Mall | 45,029,043 | 8,019,823,960 | 409,217 | 17,882,256 |
| Fall | 40,619,889 | 5,688,511,814 | 250,308 | 7,932,283 |
| All | 85,648,933 | 13,708,335,774 | 659,525 | 25,814,539 |

For those who may wish to study the data further on their own, a database, in .csv format, is available. The database has the modified data as summarized in Table 4. Its format is similar to that published in the latest CIA individual life mortality study for individual policy years 2009–2010 to 2018–2019.

Table 5 shows the progression from the original data to the data used in construction. A/E ratios are calculated on CIA9704 with improvement on MI-2017 and also on CIA2014 with improvement on MI-2017. Excluding experience after the first renewal of renewable term has the largest impact. Replacing actual face amounts with $1.5 million for amounts of $1 million and up has little impact on exposure, but a larger impact on death claims; the A/E ratios increase by about 1%. The other adjustments are essentially neutral. Note that the original data is represented by the second row of the table, and the modified data by the last row.

CIA2014 uses more years of data than earlier CIA tables. The main reason for doing so is to be able to determine the rates in the select period with more precision. If only five years of data were used, standard deviations in raw mortality rates would be higher by about 40% on average.

**Table 5. Progression from all data to that used in constructing CIA2014. Expected given on two tables**

| | Amounts in millions | | A/E with MI-2017 | |
|---|---|---|---|---|
| | **Exposure** | **Deaths** | **CIA9704** | **CIA2014** |
| All in mortality study | 14,426,554 | 28,271.6 | 93.926% | 102.799% |
| Exclude renewals | 13,666,463 | 25,914.8 | 91.450% | 99.401% |
| Remove anomalies | 13,666,452 | 25,906.3 | 91.422% | 99.371% |
| Bands 7&8 at $1.5m | 13,708,339 | 25,654.1 | 92.435% | 100.394% |
| Adjust to 2014 | 13,708,336 | 25,814.5 | 92.408% | 100.351% |

### 3.5.6 Variations by size

For the main table construction, variations by face amount are ignored and all size bands are combined. However, there is a strong trend of decreasing mortality as the bands increase in size. It is important to be aware of the effect because the distribution of exposure across the size bands differs by age and duration. Generally average size decreases with duration, and the mid-range of ages has a higher average size than either the older or younger ages.

Table 6 shows the A/E ratios for each size band for the original data. The database provided by the CIA includes eight size bands. (When the modified data is used, only seven size bands are shown because all amounts of $1 million or more are changed to $1.5 million, which lies in Band 7.) The ages included are limited to issue ages 16–75 and ultimate to age 90 for this table.

**Table 6. A/E ratios by size band. Expected on CIA9704 with MI-2017. Issue ages 16–75. Original data**

| Size Band | Amount Range | Exposure (millions) | | A/E | | Std Deviation | |
|---|---|---|---|---|---|---|---|
| | | Male | Female | Male | Female | Male | Female |
| 1 | (0–10k) | 19,966 | 15,042 | 127.1% | 127.2% | 0.3% | 0.5% |
| 2 | (10–50k) | 234,477 | 223,437 | 115.6% | 109.3% | 0.3% | 0.4% |
| 3 | (50–100k) | 348,157 | 330,360 | 100.6% | 92.3% | 0.5% | 0.7% |
| 4 | (100–250k) | 1,240,817 | 1,148,422 | 93.5% | 84.6% | 0.6% | 0.8% |
| 5 | (250–500k) | 1,437,566 | 1,263,403 | 85.7% | 78.5% | 1.0% | 1.5% |
| 6 | (500k–1m) | 1,788,056 | 1,268,532 | 82.8% | 81.8% | 1.4% | 2.3% |
| 7 | (1m–2m) | 1,419,109 | 627,657 | 79.1% | 70.5% | 2.2% | 4.1% |
| 8 | 2m+ | 1,213,174 | 357,565 | 73.4% | 53.1% | 5.0% | 10.6% |
| all | 1+ | 7,701,324 | 5,234,418 | 91.7% | 87.0% | 0.7% | 0.9% |

The variation by band is statistically significant. The work done in the next few sections continues the traditional approach of ignoring variation by size band, but look to Section 11 for approaches that modify the data further to recognize variations by size band.

# 4 Fundamentals of construction

## 4.1 Graduation method

There are many methods of graduation, but in recent decades three have predominated: Whittaker–Henderson (WH) graduation, parametric graduation, and penalized splines. The 2015VBT of the Society of Actuaries (SOA) is an exception; it was constructed using a generalized additive model.

WH achieves a balance between fit and smoothness, but makes no assumption of the shape of the resulting curve. Several recently developed mortality tables and improvement scales of the CIA and the SOA have used this method.

Parametric graduation begins with choosing an algebraic formula that is believed to fit the underlying data, and then through least-squares regression, or a similar technique, the parameters of the formula are determined. The result will be good only if the formula is suitable. Parametric graduation was used for CIA8288, CIA8692, and CIA9704 in the select period.

Penalized splines are popular in the UK, but they have not been used much in North America. WH is a special case of penalized splines, and penalized splines can be thought of as a piecewise parametric graduation.

This paper uses the first two approaches, but WH predominates. In particular, the main departure from the method used with earlier CIA tables is that two-dimensional WH is used for the main graduation of the select period. This is in contrast to the parametric model developed by Panjer and Russo and used for CIA8288, CIA8692, and CIA9704. WH makes no assumption about the shape of the select table, and therefore it lets the data speak for itself to a greater extent.

The standard expression minimized by the WH method is given below:

$$\sum Wt(Grad - Raw)^2 + h\sum(\Delta^n Grad)^2$$

The first term is an expression for the goodness of fit of the graduated values to the raw; the second is an expression for the degree of smoothness of the graduated values. With order *n* graduation, the *n*-th difference is minimized for smoothness, and a perfectly smooth curve is a polynomial of order *n* - 1.

When mortality rates are being graduated, the weights are typically the exposure. When A/E ratios are being graduated, the weights are more appropriately the expected. In these two cases it is a feature of WH that the sum of death claims and the average age at death are the same for both raw and graduated rates. The weights are always normalized, by multiplying by a factor, so that they add to the number of numbers being graduated; doing so keeps the value of *h* in a reasonably narrow range across many sets of data.

Walter Lowrie developed a variation of WH which treats perfect smoothness as an exponential with base (1 + *r*) plus a polynomial of order *n* - 2. This variation is particularly useful for curves that are known to be close to exponential, such as mortality rates. The expression to be minimized with Lowrie's variation is

$$\sum Wt(Grad - Raw)^2 + h\sum(\Delta^n Grad - r\Delta^{n-1} Grad)^2$$

WH can also be used in two dimensions. Fit is determined across the whole matrix, and smoothness is defined in both horizontal (usually policy years) and vertical (usually ages) directions. The expression to be minimized is then

$$\sum\sum(Wt(Grad - Raw)^2 + h\sum\sum({}_h\Delta^m Grad)^2 + v\sum\sum({}_v\Delta^n Grad)^2$$

All three types of WH were used in testing, but Lowrie's variation was not used in the final construction.

Any one-dimensional graduation method struggles with the accuracy at the ends of the range, and any two-dimensional graduation method struggles with the accuracy at the edges of the matrix, particularly if there be less weight at the ends or edges. It is common to graduate over more ages/policy years than will eventually be used; the less accurate values are dropped. For a select table, it is not practical to drop off any policy years, but fortunately the amount of exposure does not decrease too rapidly at higher policy years, and by its nature tends to be highest at the early policy years.

## 4.2 Building in sections

One rarely has the luxury of an abundance of data at all ages and policy years, and certainly not in the present case. There is substantially less data at low and high ages. There is no useable data at the highest ages. Accordingly, it is more appropriate to build the table in sections to be pieced together rather than as a single graduation over the whole range of ages and policy years. This makes the task more complex, but it is common practice and has been used for all tables developed for the CIA.

There are four main sections: adult ultimate, adult select, juvenile ages, and oldest ages. There are techniques for joining the sections together. There are some differences in the method for all smoking classes combined as opposed to smoking-distinct classes. All are described below.

## 4.3 Select period

Since mortality table C.A. 1969–75, all CIA life insurance tables have used a 15-year select period. As will be shown below, the effect of selection continues beyond 15 years, but in decreasing magnitude. It is also an open question whether we are observing the effect of selection or the effect of variation by size because average size decreases with increasing duration.

The choice of selection period involves a compromise. If the period be set too short, the ultimate rates may be low and give rise to inadequate valuation of older business. If the period be set too long, there may be a shortage of data in the ultimate with the result that the ultimate rates are less well supported. Because the graduation is less credible where data is scarce, the high policy year select rates may be influenced too much by smoothness and not enough by fit.

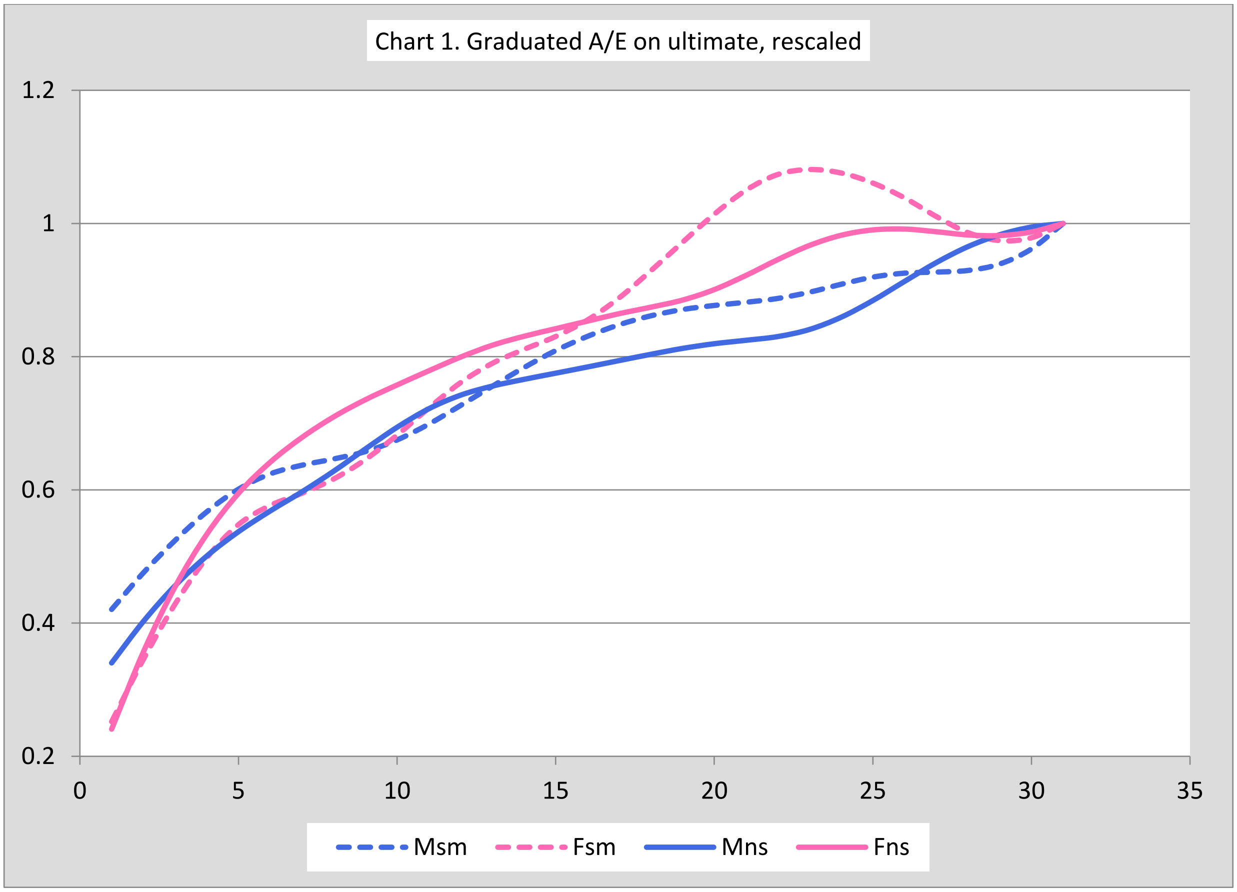
Table 7 shows A/E ratios with expected on CIA9704 ultimate applied by attained age regardless of policy year for the exposure. The data used include issue ages 16–70 and size Bands 3 and up (minimum of $50,000).

**Table 7. A/E for issue ages 16–70. Expected on ultimate CIA9704 with MI-2017. Bands 3–7 combined**

| | Policy Years | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1–5 | 6–10 | 11–15 | 16–20 | 21–25 | 26–30 | >30 |
| Msm | 55.6% | 70.2% | 83.0% | 91.8% | 97.0% | 100.4% | 109.5% |
| Fsm | 47.7% | 66.8% | 87.7% | 102.0% | 116.6% | 112.8% | 111.2% |
| Mns | 45.6% | 64.1% | 77.7% | 82.2% | 86.3% | 98.1% | 102.3% |
| Fns | 40.1% | 63.4% | 73.9% | 79.4% | 87.6% | 90.2% | 92.1% |
| Total | 45.2% | 64.6% | 77.4% | 83.1% | 89.0% | 97.4% | 102.2% |

If the effect of selection were limited to 15 years, one would see fairly flat A/E after the first 15 policy years, but that is not what we see. It seems evident that the effect of selection continues farther, but to a lesser extent. Testing shows a similar pattern for narrower groups of issue ages and size bands.

Chart 1 is based on the same data as Table 7, but the A/E ratios are graduated moderately and the ratios are then scaled to be 1.0 for policy years greater than 30 by dividing the graduated A/E ratios by the ratio for policy years greater than 30.




One might conclude that a longer select period is better, but then there is less data on which to build the ultimate table. Table 8 shows the standard deviation in A/E for various years at which the ultimate might start. The underlying data are the same as used for Table 7.

**Table 8. Standard deviation in A/E for issue ages 16–70. Bands 3–7 combined**

| | Ultimate Starting after Policy Year | | | | |
|---|---|---|---|---|---|
| | **10** | **15** | **20** | **25** | **30** |
| Msm | 1.5% | 1.6% | 1.8% | 2.1% | 3.4% |
| Fsm | 2.2% | 2.3% | 2.6% | 3.3% | 5.7% |
| Mns | 0.7% | 0.8% | 0.9% | 1.1% | 1.8% |
| Fns | 0.9% | 1.0% | 1.2% | 1.7% | 3.0% |
| Total | 0.5% | 0.6% | 0.7% | 0.8% | 1.4% |

The standard deviation increases with the increasing year, and it accelerates as it does so. Particularly for females, there is a large increase in standard deviation from 20 to 25 years for ultimate. The table suggests that ultimate starting after 20 years will strike a good compromise. Accordingly, the select period is set at 20 years.

# 5 Ultimate

Policy years higher than 20 are combined by attained ages as the ultimate experience. There is substantially more exposure for ages of the ultimate period than for most age-policy year cells of the select period. Accordingly, it makes sense to start with the ultimate section of the table and use it as an anchor for the rest.

The next several subsections set out the construction method for various parts of the ultimate table. Subsection 5.5 discusses how well the ultimate rates fit experience.

## 5.1 Adults, all smoking classes

The graduation uses ultimate data, by attained age, for ages 36–100, separately by sex, combining the three smoker classifications: non-smoker, smoker, and unknown. The weights are the exposure normalized. The values to be graduated are the raw mortality rates.

Because mortality rates tend to increase exponentially over most of the adult ages, it makes sense to try Lowrie's variation of WH. However, testing showed that there was no improvement in fit compared to traditional WH. Accordingly, the traditional was preferred as simpler because it does not require a parameter for the rate of growth.

The order of difference and the balancing factor (*h* in for the formula in Subsection 4.1) cannot be determined objectively. Rather, they are chosen by observing the goodness of fit and the smoothness of various trials. For both males and females, the choice was to use order 4 and balance 100. Thus, perfect smoothness is represented by a cubic equation.

(If *h* were set very high, the resulting rates would be a least-squares fit to a cubic, but fit would then suffer. If *h* were set very low, the resulting rates would match the raw rates, but the smoothness would be very poor.)

## 5.2 Juveniles

The curve of juvenile rates is markedly different from that of the adult rates. The juvenile rates start high and decrease with age for several years, are fairly flat for several years, and then begin to rise. The adult rates increase consistently over all ages. There is also substantially less exposure at the juvenile ages than at any adult age until well into the 80s.

Although there may be some effect of selection at juvenile ages, it is very difficult to quantify it because of insufficient data. Accordingly, the juvenile section of the table is organized by attained age without regard to duration from issue. The graduation is based on data for issue ages 0–20 combined by attained age.

Because of the sharp decrease in mortality rates over the first three years of age, it is not practical to include ages 0 and 1 in the graduation. Therefore, the raw mortality rates are used for these ages.

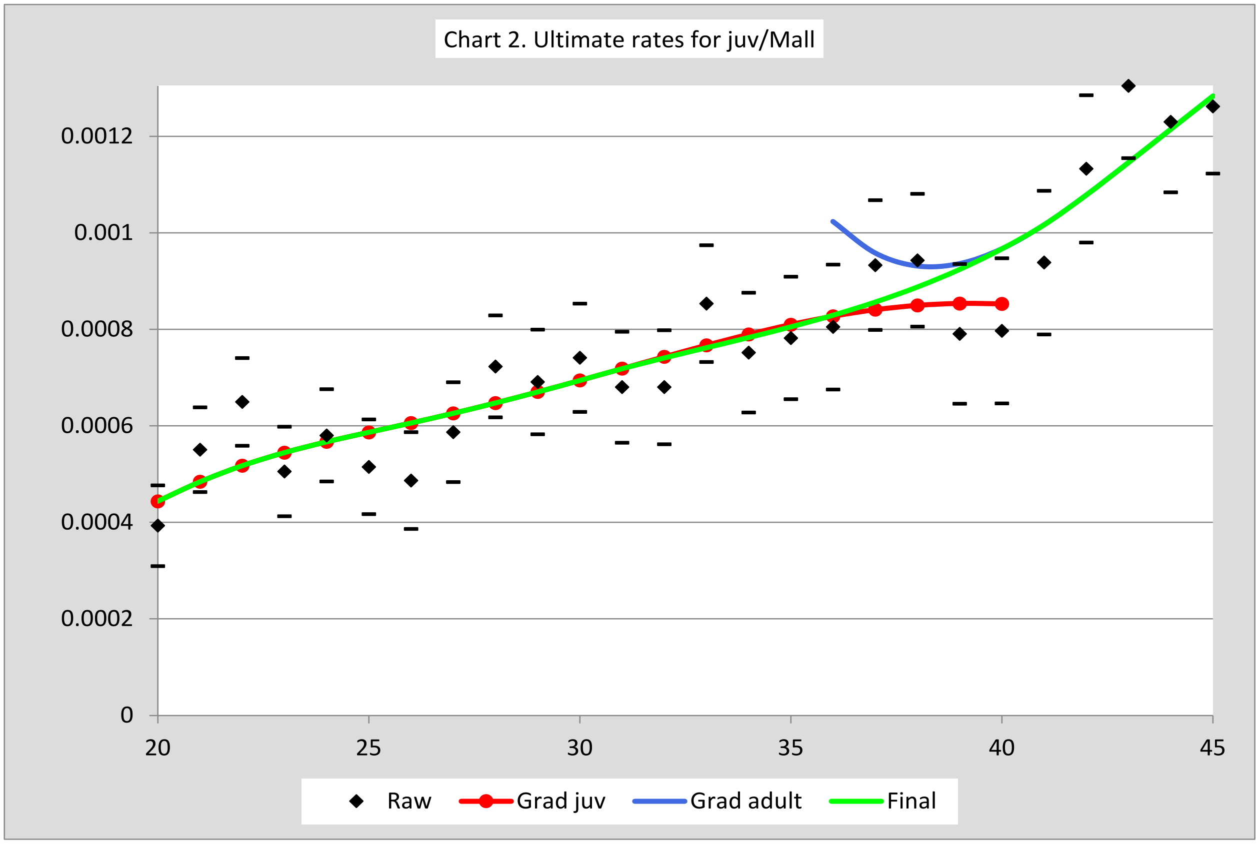
The graduation starts at age 2. It continues to age 40. The higher ages of the graduation cannot be considered "juvenile" by any normal definition, but it is useful to include these ages to ensure that the resulting mortality curve fits well into the high 20s and 30s of attained age. The weights for the graduation are the exposure. The order of difference is 3 and the balance factor is 300.

The resulting male rates are higher for age 2 than for age 1. To give a more reasonable result, these two rates are switched. No adjustments were needed for females.

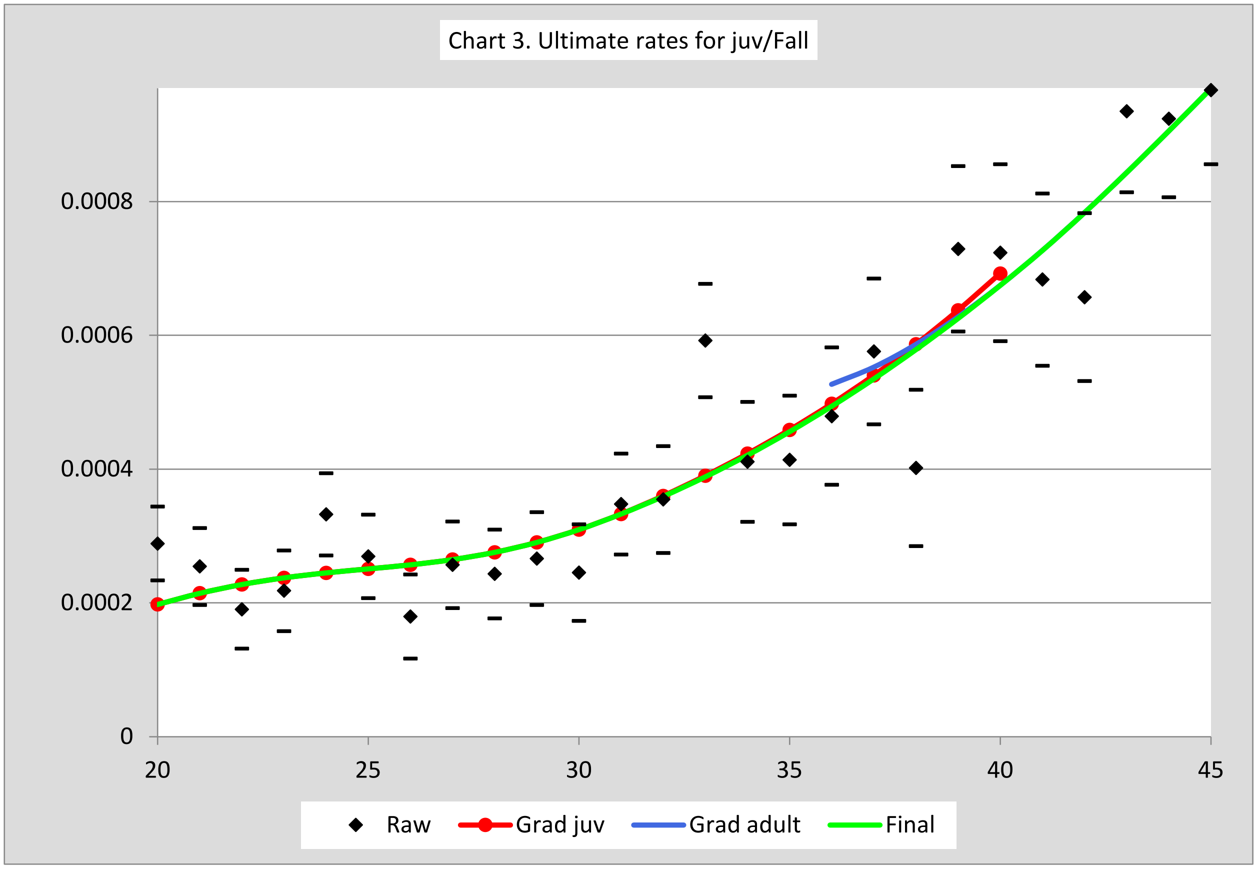
The final ultimate rates are taken from the juvenile graduation for attained age 31 and younger. The adult ultimate rates are used for attained ages 40 and higher. The rates for ages 32–39 are obtained by fitting a cubic[7] to the rates for ages 30, 31, 40, and 41.

[7] Sections of the table are usually joined by polynomial or log polynomial equations. In this case, for example, a cubic polynomial is fit to the mortality rates taken from the two sides of the gap. The interpolated values are used to fill the gap between the two sets of rates. When a log polynomial equation is used, the interpolation is done on the logarithm of the mortality rates.

Chart 2 shows the raw rates, represented by black diamonds with tick marks above and below for one standard deviation. The graduated juvenile rates are in red, the graduated adult rates in sky blue, and the final rates in lime green. The green line is acceptable because it rarely falls outside the pairs of tick marks; that is, it is always close, statistically speaking, to the raw rates.



The same process is used for female. Chart 3 illustrates the female juvenile graduation and interpolation.




## 5.3 Oldest ages

Rates at the highest ages are important to the table, but experience at those ages is not only scant but also unreliable. At the highest ages, contact may be lost with a life insured, and a death may occur without notice to the company. The policy may be left with status "alive" long after a death occurs. Such cases, even if the death be eventually reported, result in a significant understating of mortality rates, particularly over age 100.

Accordingly, rates at the oldest ages are extrapolated by fitting a Kannisto[8] curve to the experience for ages 85–95 by the method used by Ahmadi and Brown, except that it is applied to the force of mortality rather than to mortality rates. The extrapolated rates are used in the final table for ages 105–114. The rates for ages 94–104 are obtained by fitting a log cubic to the rates for ages 92 and 93 from the adult graduation described above and the rates for ages 105 and 106 from the Kannisto curve.

One might wonder whether the extrapolation is appropriate, particularly in light of the uncertainty about some of the raw rates. Charts 4 and 5 compare mortality rates from different sources of data, for males and females, respectively. The black diamonds are the raw mortality rates from the modified data. The red line results from the graduation described in Subsection 5.1. The sky-blue line shows the extrapolation described in the preceding paragraph. The green line is an extrapolation from Old Age Security (OAS) data for ages 85–95 by the same method. The magenta line is an extrapolation from the death records available through the Human Mortality Database (HMD) for Canada, using the method in Howard[9] (2011). The orange circles show raw mortality rates for supercentenarians whose ages at birth and death have been verified by the Gerontology Research Group.

[8] The Kannisto curve is of the form $\mu_x = e^{ax+b}/(1+e^{ax+b})$. The force of mortality is estimated from the raw mortality rates by the usual approximation $\mu_{x+1/2} = -\log(1-q_x)$.

[9] This method was described in a paper presented at the Living to 100 Symposium in 2011. It is an extension of the method of extinguished cohorts.

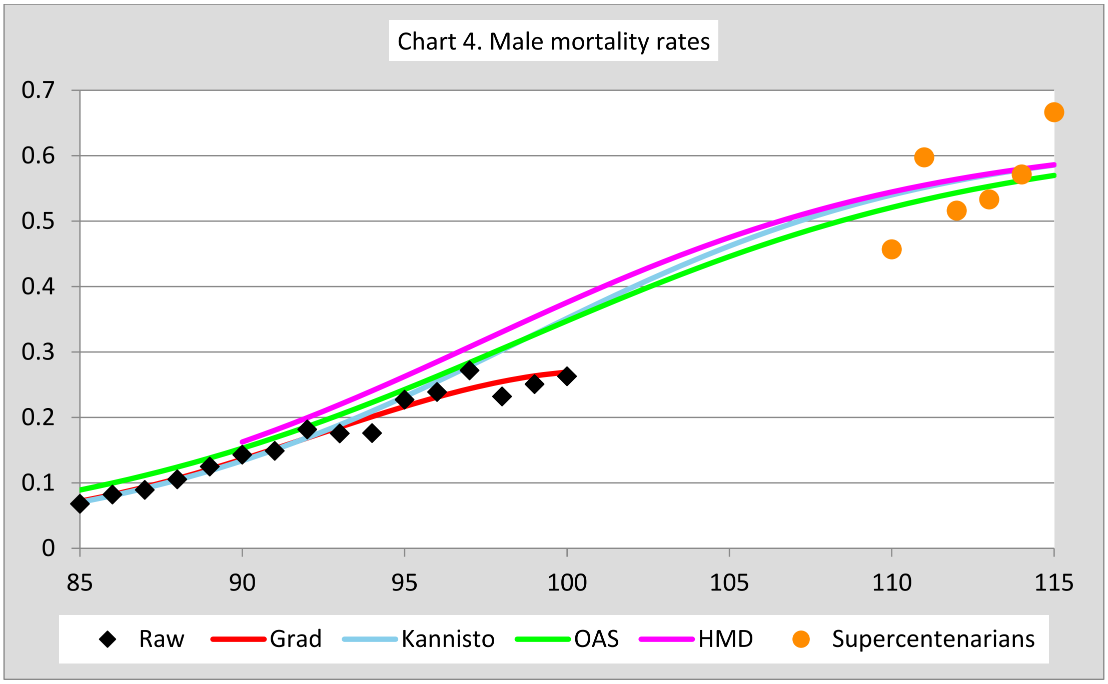


Chart 4. Male mortality rates
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
85
90
95
100
105
110
115
Raw
Grad
Kannisto
OAS
HMD
Supercentenarians

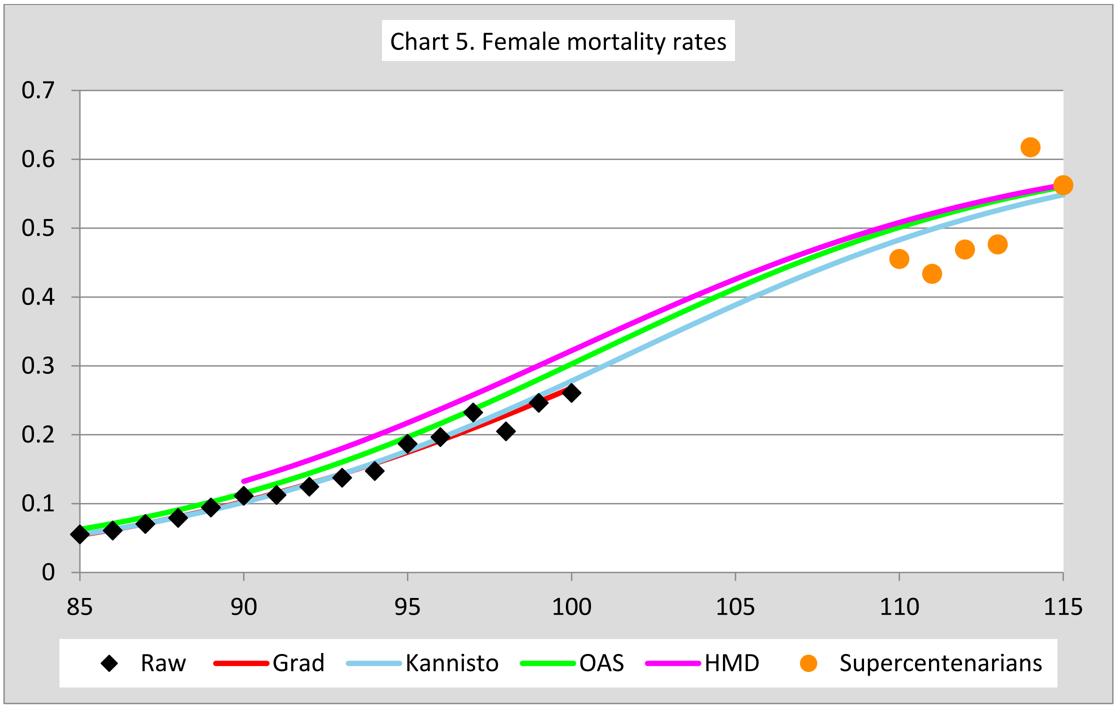


Chart 5. Female mortality rates
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
85
90
95
100
105
110
115
Raw
Grad
Kannisto
OAS
HMD
Supercentenarians

The similarity in rates corroborates the method described above for CIA2014.

The mortality rate for age 115 is set to 1.0, and thus all are assumed to die before reaching age 116. Some may object that age 116 is too "young." However, only one Canadian female has lived past exact age 116, and the oldest Canadian male died before exact age 112. For pricing purposes, there is no difference in premium rates for a terminal age of 115 compared to 120. For valuation purposes, there can be differences in the values for specific policies at very high ages, but the impact on the overall valuation is far from material. Because the rates over age 115 would not be based on any experience, it seems that the usefulness of rates over age 115 is more apparent than real.

## 5.4 Smoking-distinct

For this section, the four smoking classes are abbreviated as SM, NS, UNK, and ALL.

There are distinct differences in the data for juvenile issue ages and adult issue ages. Company practice differs on the minimum age at which the life insured is asked about smoking habits. For those issued on the basis of UNK, company practice differs on the ages at which the policy may change to SM or NS, if at all. The data shows that there are almost no UNK cases for issue ages over 18. But, of course, these lives do not enter the ultimate until age 39 or later.

Therefore, for SM and NS, there is very little reliable ultimate data under about age 45. Some variation in method is necessary.

The ultimate rates for ages under 16 are taken directly from the rates for ALL. The rates for UNK are calculated in the same manner as for ALL, but rates under age 16 are not used. The rates for SM and NS for ages 16–40 are calculated as a multiple of the rates for ALL. That multiple is determined so as to minimize the squared difference between the raw mortality rates and the rates for ALL times the multiple; the squares are weighted by the actual exposure at each age. The multiples are shown in Table 9.

**Table 9. Multiple of all smoker combined used for smoker-distinct risk classes for issue ages 0–20 and attained age 16–40**

| Msm | Fsm | Mns | Fns |
|---|---|---|---|
| 1.3047 | 1.1940 | 0.7799 | 0.8430 |

For SM, NS, and UNK, the main graduation is done in the same manner as for ALL except that the balance factor is 300, 300, 100, 100, 300, and 300 for Msm, Fsm, Mns, Fns, Munk, and Funk respectively. The interpolation between juvenile and adult is over the same ages as for ALL.

The rates for ALL are used for ages 105–115 for all risk classes, and the bridge between ages 93 and 105 is constructed in the same manner as for ALL.

## 5.5 Assessment

The most important evidence for whether a table is satisfactory is how well it fits the experience. Table 10 shows A/E[10] ratios for each risk class and for various age groups. The most important column to consider is the middle one, because ages 40–93 come from the main graduation. The last column is also important because it represents the full dataset of ultimate experience.

[10] A/E ratios being close to 100% is a necessary condition for a good fit between the data and the table, but not a sufficient condition. WH graduation ensures that there is a good weighted least-squares fit, consistent with the desired smoothness.

| Table 10. A/E claims on ultimate table. Age ranges are of attained ages | | | | | | |
|---|---|---|---|---|---|---|
| | **0–15** | **16–39** | **40–93** | **94–100** | **21–100** | **0–100** |
| Msm | | 101.8% | 100.1% | 86.8% | 100.1% | 100.1% |
| Fsm | | 102.2% | 99.9% | 99.3% | 100.1% | 100.0% |
| Mns | | 103.4% | 100.1% | 96.2% | 99.9% | 100.0% |
| Fns | | 114.7% | 100.0% | 102.0% | 100.3% | 100.3% |
| Munk | 95.3% | 102.3% | 100.0% | 90.8% | 99.6% | 99.6% |
| Funk | 100.4% | 102.2% | 100.0% | 94.6% | 99.7% | 99.6% |
| Mall | 95.3% | 104.7% | 100.1% | 93.0% | 99.8% | 99.9% |
| Fall | 100.4% | 108.9% | 100.0% | 99.5% | 100.1% | 100.1% |

Some might object that the measure of fit is artificial because it uses modified data. Table 11 shows a more traditional calculation of A/E. The original data is used; there is no modification in Band 7 and death claims are not adjusted for mortality improvement. The expected is calculated on the rates as described in this section for CIA2014 with mortality improvement applied from 2014 on MI-2017 to the appropriate year. The overall A/E is not as close as with Table 10, but still acceptable. As might be expected because of the greater volatility in the original data, the difference in A/E from 100% are generally larger for Table 11 than for Table 10.

**Table 11. A/E claims on ultimate table with improvement on MI-2017. Original data. Age ranges are of attained ages**

| | 0–15 | 16–39 | 40–93 | 94–100 | 25–100 | 0–100 |
|---|---|---|---|---|---|---|
| Msm | | 99.4% | 99.0% | 86.1% | 98.9% | 98.9% |
| Fsm | | 100.9% | 100.7% | 115.6% | 100.9% | 100.9% |
| Mns | | 102.6% | 99.5% | 107.1% | 99.7% | 99.7% |
| Fns | | 110.3% | 99.2% | 99.3% | 99.3% | 99.4% |
| Munk | 91.8% | 99.4% | 100.0% | 92.2% | 99.6% | 99.5% |
| Funk | 96.6% | 99.8% | 99.9% | 94.6% | 99.5% | 99.4% |
| Mall | 91.8% | 102.5% | 99.6% | 98.4% | 99.5% | 99.6% |
| Fall | 96.6% | 106.1% | 99.6% | 98.5% | 99.6% | 99.7% |

There are two particularly large discrepancies between Table 11 and Table 10, for Fsm and Mns, both in ages 94–100. The reason is that there were two unusually large claims: one for $3.45 million for an Fsm age 94 and one for $15 million for an Mns age 97. Apart from those claims, the A/E ratios would have been very close. It is not surprising that fluctuation can have a big influence in cells with relatively little exposure.

Chart 6 shows for Mall the raw mortality rates as a black diamond, one standard deviation above and below as a black dash, the graduated rates as a red line, and the final rates (as described above) as a sky-blue line. This risk class has the largest total exposure and in the middle range of ages all the marks and lines come together. This shows that the final rates are well attested in the data. The following chart, Chart 7, is for Fsm, which is the risk class with the least exposure. There can be less certainty about the final rates, but it is clear that the rates are well supported by the data.

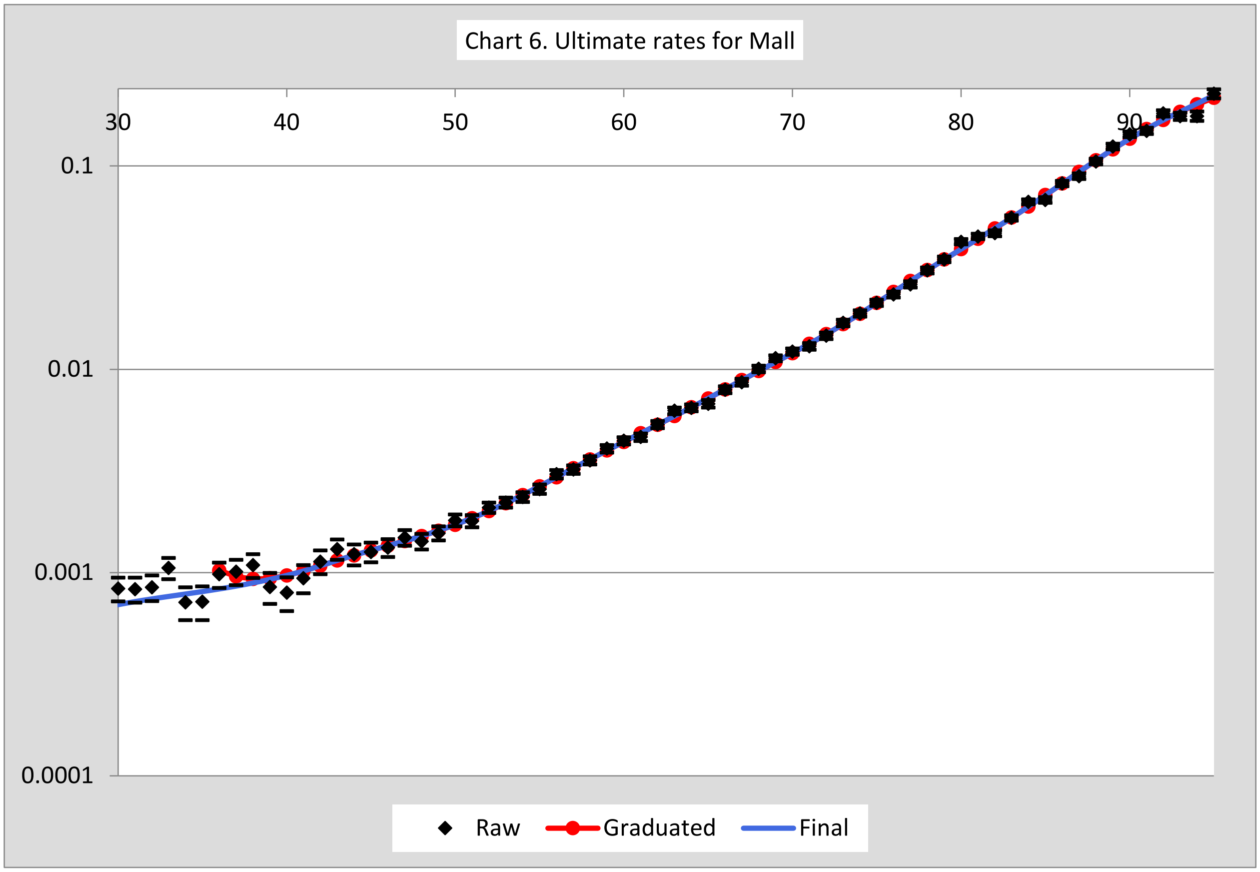
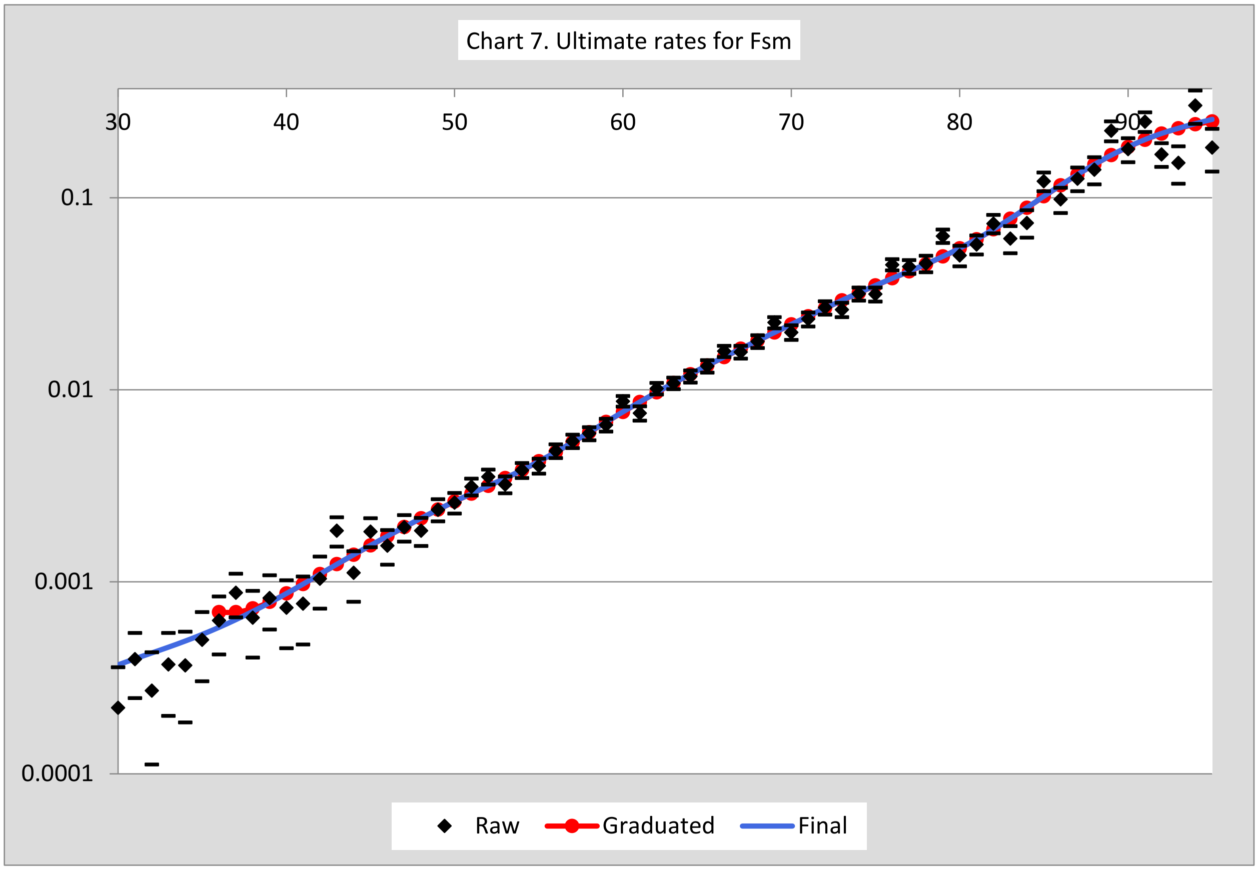


Chart 6. Ultimate rates for Mall
30
40
50
60
70
80
90
0.1
0.01
0.001
0.0001
Raw
Graduated
Final




It is also worth considering anomalies in the calculated rates; in particular, instances in which the expected pattern by sex or age is inverted. We expect female rates to be lower than male, and we expect mortality rates to increase with age after the first few years of age. There are no inversions by age; the "hump" in mortality for males in their 20s is absent. It is a surprise, but not a concern, that the slope in rates during those ages is less for females than for males. There are no inversions by sex except for smokers, which are inverted for ages 89–94. This would be a concern, but it seems to be a feature of the data. (See Section 8 for more information.)

# 6 Select

Because all the experience in the CIA study is on individually underwritten lives, one expects that, for the same attained age, the earlier the policy year, the lower the mortality rate. This is referred to as the effect of selection. The effect of selection will run off over time. As discussed in Subsection 4.3, the length of the select period was chosen to be 20 years. There are two subsequent questions to answer: "What is the pattern of the run-off of the effect of selection?" and "How dependent is the pattern of run-off on age at issue?"

## 6.1 Observing the effect of selection

Traditionally, actuaries have studied the effect of selection as a ratio between select mortality rates and ultimate mortality rates for the same attained age.

$$q_{[x]+t}/q_{x+t}$$

Because there is so much statistical fluctuation in age-duration cells of the mortality study, it is necessary to combine several years of data before any pattern can be observed. There are two obvious alternatives: summarize data for a group of issue ages and summarize for a group of attained ages. The observed pattern differs depending on the choice of issue or attained, but testing indicates that the difference is small. The work presented here is by issue age because data is collected by issue age and because the table is constructed by issue age.

Charts 8 and 9 compare select and ultimate mortality by calculating the ratio of actual claims during the select period to the product of exposure for the same period and ultimate mortality rates calculated above for the appropriate attained age. The calculation is done for adult males and females for issue ages 20–79. The black diamonds show the actual-to-tabular[11] (A/T) ratios from the data. The red line shows the weighted average select/ultimate ratio for CIA2014 (after the full table was constructed). The patterns are

[11] "Tabular" is used rather than "expected" because one does not expect mortality to be at the ultimate level in the early policy years. However, the calculation is analogous to A/E; the mortality rates are taken from the table but are based on attained age rather than issue age and policy year.

similar for males and female, but the female starts lower and increases more quickly than the male.

Chart 8. A/T on ult, Mall, issue ages 20–79

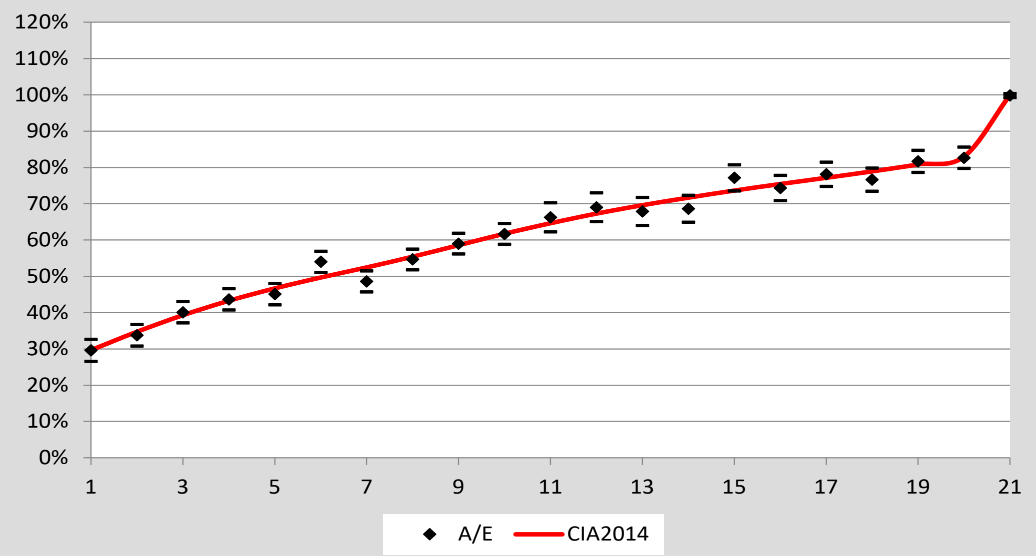
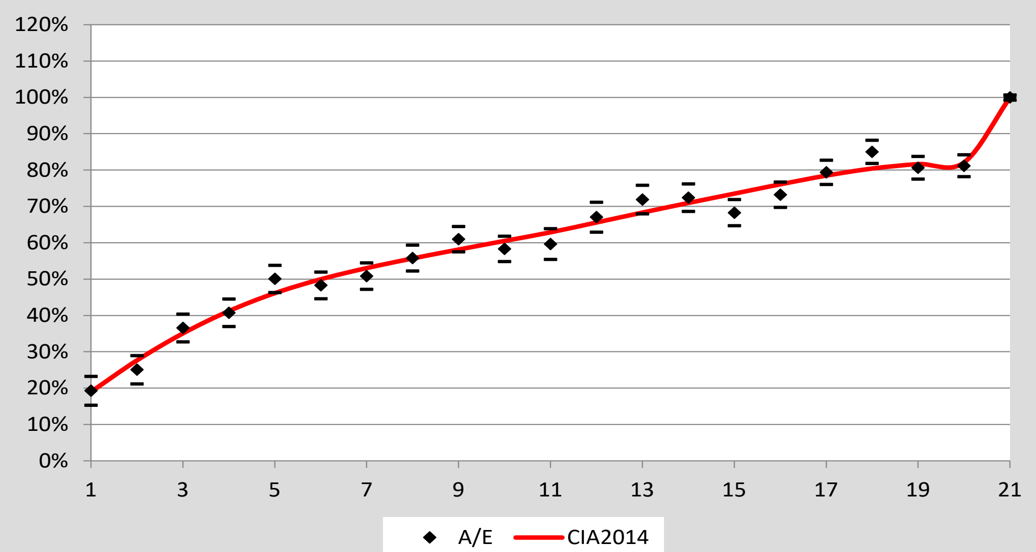
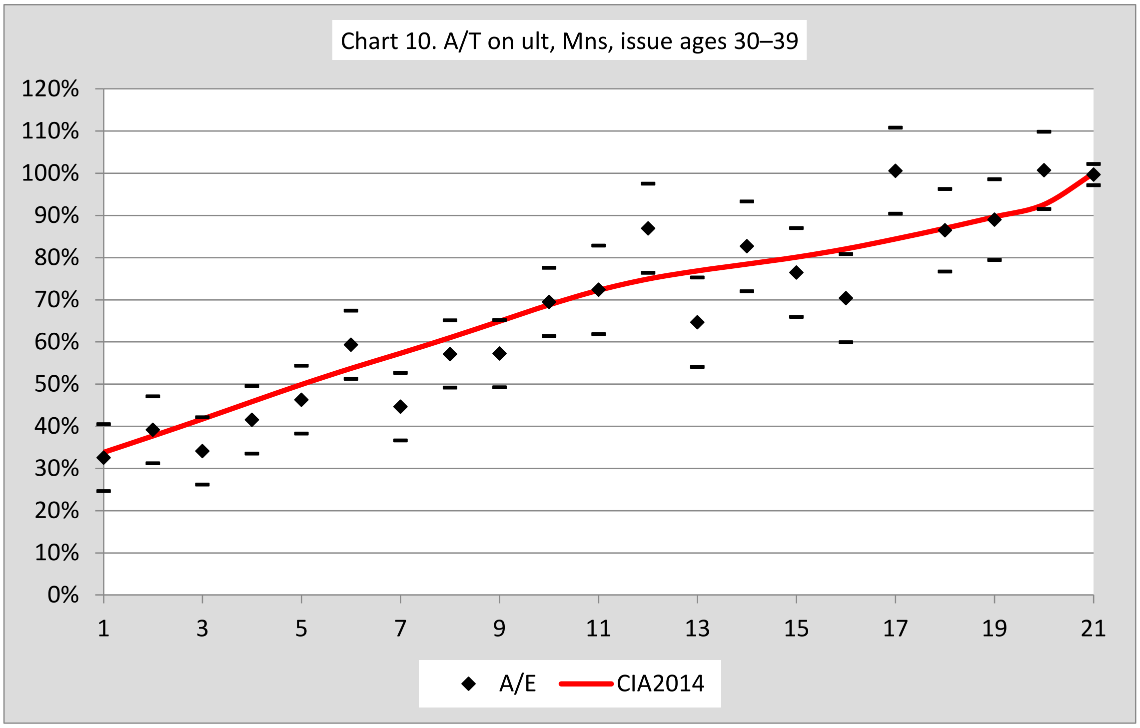
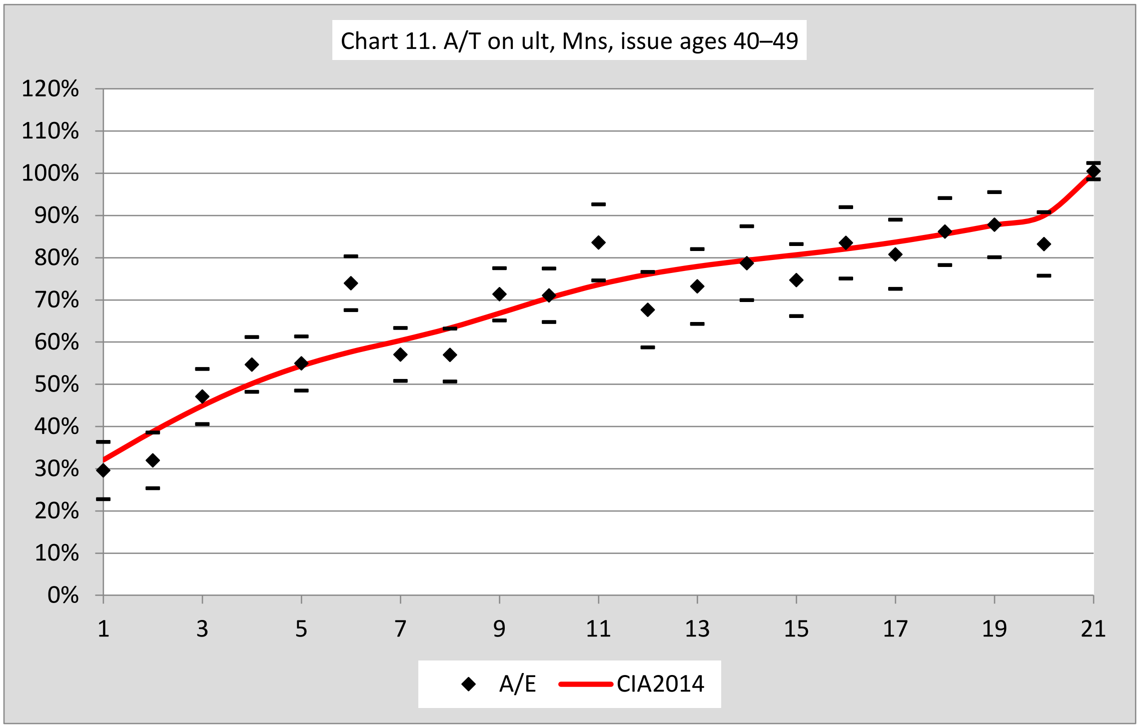



Chart 9. A/T on ult, Fall, issue ages 20–79



But is the pattern of ratio similar for all issue ages? Charts 10 and 11 are for male non-smokers for two successive decennial issue age groups. Both start, in the first policy year, at about the same value, but thereafter they diverge. The 30s progress in nearly a straight line to 100% after policy year 20. The 40s follow a more pronounced "S" curve, initially rising faster than the 30s, but later much slower, with a flatter section for policy years 14–17.






Charts for other risk classes and other age groups show noticeable variation. It seems reasonable to conclude that there is no consistent pattern for the effect of selection. Accordingly, WH graduation seems preferred for this dataset to parametric graduation. In this way the data can speak for itself rather than imposing a specific form of curve.

## 6.2 Two-dimensional graduation

The select portion of the table is obtained by graduating the ratio of actual claims to tabular claims on the ultimate table already constructed. The weights are the tabular claims. (By graduating A/T with the tabular as weights, WH maintains total claims over the graduation and the average age at claim.) The graduation is performed over policy years 1 to 20; a discontinuity is allowed between the last select policy year and the ultimate. The graduation could have extended to policy year 21 (the ultimate); that would have resulted in a smoother transition between select and ultimate, but the fit to the select experience would have suffered.

The adult graduation is done over issue ages 21 to 85, separately for six of the eight risk classes. (There is insufficient data in the select period to develop rates for Munk and Funk.) Table 12 shows the WH parameters for each risk class. Because there is much less variation by age than by policy year, the vertical order is 1, implying that perfect smoothness is a horizontal line. The horizontal order of difference is 3 in most cases to support the convexity that appeared to be in the data. However, in one case, the order was set to 2 because there seemed to be spurious complexity in the A/T ratios at order 3. The graduated ratios are multiplied by the ultimate rates to determine the select rates at each age-policy year.

**Table 12. Graduation parameters for select**

| Risk Class | Horizontal (PolYr) | | Vertical (Age) | |
|---|---|---|---|---|
| | Order | Balance | Order | Balance |
| Msm | 3 | 60 | 1 | 200 |
| Fsm | 2 | 150 | 1 | 200 |
| Mns | 3 | 20 | 1 | 100 |
| Fns | 3 | 25 | 1 | 100 |
| Mall | 3 | 15 | 1 | 75 |
| Fall | 3 | 20 | 1 | 100 |

Table 13 shows why the select rates for Munk and Funk were not calculated. One should also note that the exposure for Msm and Fsm is substantially less than for Mns and Fns. Table 13 includes issue ages 25–85 for the first 20 policy years and attained ages 45–105 for ultimate.

**Table 13. Exposure and average size for issue ages 25–85. Includes policy years 2009–2019 (exposure in millions)**

| | Policy Years 1–10 | | Policy Years 11–20 | | Ultimate | |
|---|---|---|---|---|---|---|
| | Exposure | AvgSize | Exposure | AvgSize | Exposure | AvgSize |
| Msm | 508,392 | 289,430 | 93,599 | 94,954 | 82,877 | 52,540 |
| Fsm | 233,670 | 194,156 | 61,860 | 62,894 | 59,011 | 38,265 |
| Mns | 4,835,279 | 445,113 | 976,207 | 192,006 | 571,918 | 98,235 |
| Fns | 3,492,291 | 323,099 | 681,501 | 125,407 | 326,052 | 63,041 |
| Munk | 127 | 2,685 | 2,360 | 39,951 | 216,635 | 23,021 |
| Funk | 87 | 2,098 | 1,910 | 25,102 | 97,373 | 15,857 |
| Mall | 5,343,798 | 421,877 | 1,072,166 | 174,932 | 871,429 | 51,842 |
| Fall | 3,726,048 | 309,122 | 745,271 | 114,764 | 482,435 | 37,530 |

The discontinuity between the select and ultimate rates is larger than one might expect, particularly for Mall and Fall, and to some extent for Fns. For Mall and Fall, the discontinuity seems to be exacerbated by the fact that almost a quarter of the exposure in the ultimate period is from Munk and Funk, but almost none in the select period. CIA9704 had no discontinuity because the parametric graduation removed it. However, it is reasonable that there be a discontinuity because the ultimate is not equivalent to experience in the 21st policy year but rather the average for all years after the 20th. It may be that some effect of selection continues. It is certainly the case that the average size in the ultimate is less than in the select period, and one would expect some increase in mortality rates in the ultimate because of the difference in size. Therefore, the discontinuity is viewed as a feature of the underlying data and is allowed to exist in CIA2014.

## 6.3 Juvenile

Earlier tables have presented no effect of selection for some juvenile ages, such as under attained age 16. In the case of this table, the juvenile ultimate rates calculated earlier are used for issue ages 0–17. The rates for issue ages 18–24 are determined by fitting a quadratic curve to the rates for issue ages 17, 25, and 26. The calculation is done for each policy year independently.

It is admitted that this method handles the juvenile issue ages rather roughly. However, there is simply not enough data to justify a method which would try to recognize the effect of selection at younger issue ages.

## 6.4 Oldest ages

In the past, members have expressed a need for the selection portion of published tables to extend to issue age 90. The experience over issue age 80 is sparse. Consequently, the rates over age 80 must be an extrapolation, and they must be used with caution.

The rates for issue age 90 were estimated based on the ratios of select to ultimate for issue age 70 from the rates previously calculated. (Age 70 has a reasonable amount of data underlying it.) The ratios were increased by 2% for policy year 1, 4% for policy year 2, 6% for policy year 3, etc., to a maximum ratio of 100%. Those ratios were applied to the ultimate mortality rates to obtain the select rates for age 90. There is also a constraint that female rates not exceed 95% of the male rates. There is no estimate[12] of select mortality rates over issue age 90.

The select rates for issue ages 81–89 are from a log cubic fitting through the values for issue ages 78, 79, 80, and 90; each policy year is calculated independently.

That completes the construction of CIA2014.[13]

## 6.5 Assessment

As with the ultimate, one must check on how closely the table fits with the experience. Table 14 shows A/E ratios for each risk class and for various age groups for experience in the first 20 policy years only. The issue age group 25–80 represents the main ages graduated. The

[12] The tables in AXIS format are extended to issue age 99 using rates from the ultimate portion of the table because AXIS requires rates to issue age 99. Those rates are not appropriate for actual use. If an actuary is pricing business for issue ages over 80, and especially if over 90, it would best to develop mortality rates suitable for that application using information on how and to whom the product will be marketed.

[13] For those who are interested, the workbook used in constructing CIA2014 and associated files are available for download at www.howardfamily.ca/mortality/CIA2014.

ratios are all very near 100%. The columns to the left show other smaller age groups. We can see some variations between these columns, indicating that the fit is not always as good in some subsets. Overall, the fit seems good enough to accept the table.

**Table 14. A/E ratios on CIA2014. Age groups are of issue ages. First 20 policy years only**

| | 0–19 | 20–29 | 30–39 | 40–70 | 25–80 | 0–90 |
|---|---|---|---|---|---|---|
| Msm | 99.8% | 109.6% | 93.2% | 101.1% | 99.7% | 99.9% |
| Fsm | 103.0% | 98.6% | 98.6% | 98.8% | 100.0% | 100.0% |
| Mns | 107.0% | 111.0% | 96.7% | 100.2% | 99.6% | 100.1% |
| Fns | 118.0% | 102.3% | 95.6% | 101.7% | 100.1% | 100.0% |
| Mall | 99.4% | 108.7% | 96.1% | 100.2% | 99.6% | 100.0% |
| Fall | 103.5% | 102.3% | 95.7% | 100.6% | 99.9% | 99.9% |

As was done for the ultimate portion of the table in Subsection 5.5, it is good to check whether the original data might lead us to a different conclusion. Table 15 is based on the same cross-sections of data as Table 14 but the original data is used instead of the modified, and the mortality improvement is handled by adjusting the new table to each year of experience using MI-2017.

**Table 15. A/E ratios on CIA2014. Age groups are of issue ages. First 20 policy years only. Original data**

| | 0–19 | 20–29 | 30–39 | 40–70 | 25–80 | 0–90 |
|---|---|---|---|---|---|---|
| Msm | 95.8% | 104.7% | 94.3% | 98.4% | 97.9% | 97.9% |
| Fsm | 101.2% | 94.2% | 98.4% | 99.9% | 100.6% | 100.6% |
| Mns | 104.2% | 107.0% | 99.6% | 98.7% | 98.5% | 98.8% |
| Fns | 107.9% | 100.0% | 94.3% | 98.4% | 97.1% | 97.2% |
| Mall | 95.7% | 104.8% | 98.8% | 98.3% | 98.3% | 98.5% |
| Fall | 97.8% | 99.7% | 94.9% | 98.1% | 97.5% | 97.7% |

The differences between tables 14 and 15 are larger than between tables 10 and 11. It turns out that the differences between tables 14 and 15 are produced by the differences in experience in size band 7 ($1 million and higher). There is virtually no difference for Bands 1–6. The purpose of the modification made in Band 7 was to decrease fluctuations, and it worked. For example, consider the lower left corner: "Fall" issue ages 0–19. Table 15 has a value 5.5% lower than Table 14. This is caused by the fact that the average exposure for amounts of at least $1 million is $2 million, but the average size claim is only $1.2 million. The modified data eliminates the fluctuation by size in the highest band because all policies in Band 7 are taken as $1.5 million. It seems reasonable to accept the new table, based on the modified data, as being representative of the experience.

Charts 12 and 13, for Mns issue age 40 and 50, illustrate how well the graduated select rates fit the raw data. The black diamonds represent the raw mortality rates for the specified issue age. The black tick marks above and below represent one standard deviation away from the mean rate. The red line shows the rates for CIA2014 in the select period. The ultimate rate for the next attained age is shown as policy year 21, although of course it represents attained age 60 or 70 for all issue ages at least 20 years younger. The discontinuity in slope after the 20th policy year is to be expected. The ultimate rates for the corresponding attained are shown in light blue for comparison. One would expect that the red lines would fall between pairs of tick marks about two-thirds of the time, and they do slightly better. The standard deviations increase with duration in part because the mortality rates increase with duration, and in part because the exposure decreases with duration.

It is important to recall that although Charts 12 and 13 show one dimension of the mortality table, the graduation is done in two dimensions. Thus, the red lines are influenced by neighbouring ages which are not shown on the charts.

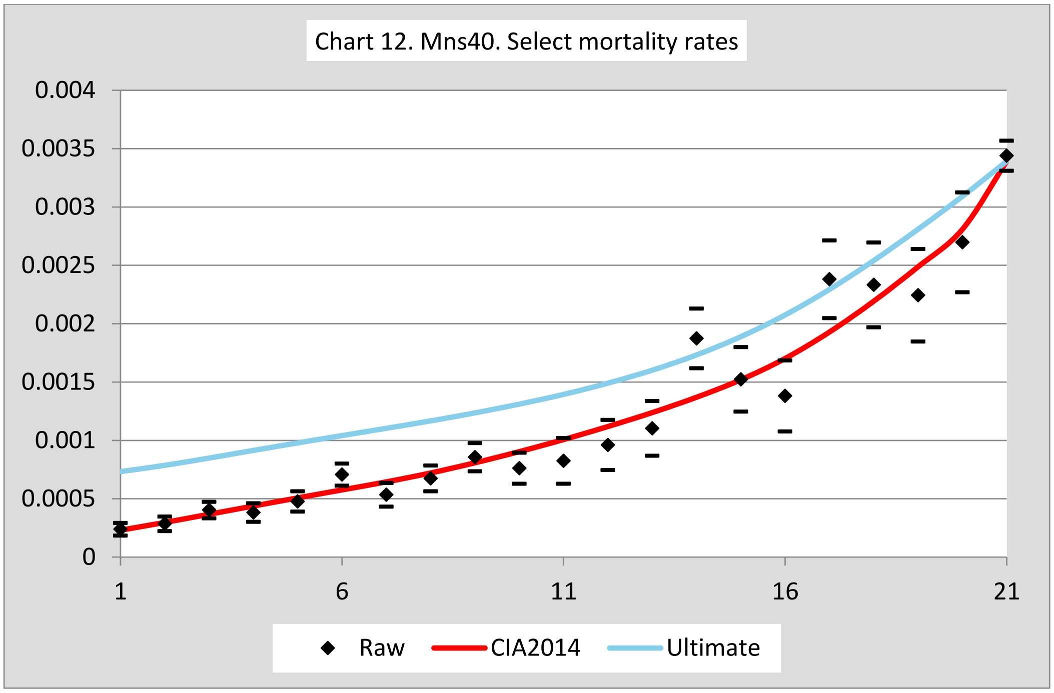


Chart 12. Mns40. Select mortality rates
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
1
6
11
16
21
Raw
CIA2014
Ultimate

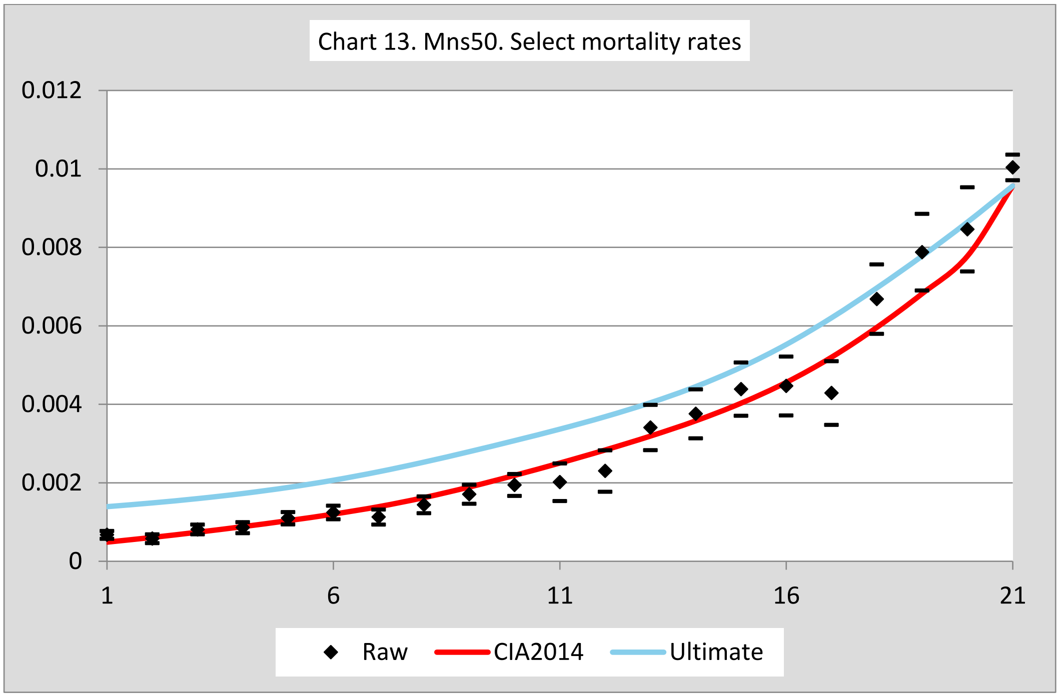


Chart 13. Mns50. Select mortality rates
0.012
0.01
0.008
0.006
0.004
0.002
0
1
6
11
16
21
Raw
CIA2014
Ultimate

It is also necessary to consider inversions during the select period. There are four types of inversions for a select table: sex inversions, vertical age inversions (same policy year, issue age varies), horizontal inversions (same issue age, policy year varies), and policy year inversions (same attained age, policy year varies). There are many inversions for issue ages up to 30 primarily because the mortality curve is not monotonic, increasing during those ages, and the shape of the curve is different for males and females. The inversions are small and not material.

There are sex inversions only for smokers, all at attained ages 88 and higher. (See Section 8.) These are allowed to persist in the final table.

At older ages there are no horizontal or vertical age inversions for females. There are not more than four for any male table. There are several diagonal age inversions. None of the inversions seem significant.

It should be noted that if parametric graduation had been used, there would be few inversions other than at the youngest ages and perhaps the hump in the 20s for males. The reason is that the expression for which parameters are found ensures that the various mortality curves are in a sense parallel to one another. If there is a portion of the experience for which there is a valid inversion, the parametric graduation would not recognize it other than to adjust all rates to achieve a least-squares fit.

Now that the table is complete, it is feasible to look at the financial impact of the new table compared to CIA9704. Tables 16 and 17 show net level premium values. This is certainly "old school." However, the values are not intended to be realistic estimates of premium rates today but only to provide a broader comparison of the two tables. The calculations are done as of the start of 2021 using improvement on MI-2017. Table 16 uses CIA9704 as the mortality table, assuming a base year of 2001. Table 17 has values calculated identically except that the new table, CIA2014, is used with a base year of 2014.

| Table 16. Values on CIA9704 and MI-2017 per $1,000 at 3% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Issue Age | 10-Yr Term Net Level Premium | | | | Whole Life Net Level Premium | | | |
| | Msm | Fsm | Mns | Fns | Msm | Fsm | Mns | Fns |
| 30 | 0.59 | 0.30 | 0.33 | 0.21 | 8.15 | 7.17 | 6.67 | 6.11 |
| 40 | 1.15 | 0.99 | 0.50 | 0.41 | 12.15 | 10.66 | 9.74 | 8.90 |
| 50 | 3.45 | 3.28 | 1.06 | 0.99 | 18.73 | 16.10 | 14.71 | 13.34 |
| 60 | 10.38 | 7.63 | 3.41 | 2.96 | 29.50 | 24.41 | 23.08 | 20.72 |
| 70 | 22.40 | 13.74 | 9.16 | 7.32 | 46.45 | 37.79 | 37.80 | 33.64 |

| Table 17. Values on CIA2014 and MI-2017 per $1,000 at 3% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Issue Age | 10-Yr Term Net Level Premium | | | | Whole Life Net Level Premium | | | |
| | Msm | Fsm | Mns | Fns | Msm | Fsm | Mns | Fns |
| 30 | 0.51 | 0.28 | 0.27 | 0.17 | 8.39 | 7.95 | 6.56 | 6.01 |
| 40 | 0.96 | 0.78 | 0.45 | 0.35 | 12.46 | 11.84 | 9.54 | 8.72 |
| 50 | 2.71 | 2.15 | 0.97 | 0.79 | 19.16 | 18.06 | 14.28 | 12.98 |
| 60 | 8.27 | 6.68 | 2.67 | 1.77 | 30.41 | 28.34 | 22.24 | 19.99 |
| 70 | 22.41 | 18.14 | 8.09 | 5.43 | 49.70 | 45.98 | 36.36 | 32.36 |

The non-smoker values are all lower on CIA2014. The term smoker rates are also lower except for female ages 30 and 70; the whole life smoker rates are all higher on CIA2014 than on CIA9704. That implies that actual mortality improvement has been stronger for non-smokers than for smokers. It is not feasible to develop a smoker-distinct improvement scale, and the assumption that future mortality improvement is not smoker-distinct remains reasonable, even if data was available. It therefore seems important to develop a new mortality table every few years to true up the differential in improvement between smokers and non-smokers.

# 7 Age last birthday

Although the proportion of life insurance sales based on age last birthday has been declining for many years, there is still a need for a table on age last. Typically, the table has been constructed from the age-nearest table using the approximation

$$q_{[x]+t}^{ALB} = (q_{[x]+t}^{ANB} + q_{[x+1]+t}^{ANB})/2$$

A careful handling of the force of mortality (which is the same for both bases) shows that the approximation tends to overstate the age-last mortality rates by about 0.25% at many ages, and less at younger and older ages.

The method used here is to fit a polynomial through five successive values of $log(l_x)$, and calculate values for $l_{x+0.5}$ and $l_{x+1.5}$ from which $q_x$ age last is calculated.

That works fine for ultimate, but theoretically should be applied to cohorts only. However, the pragmatic approach is to apply the same method to columns of the select table. That can be justified if the effect of selection is age-invariant; it is not, but the effect of selection changes slowly with age.

The general approach is not reliable for issue age 0. One must know the distribution of sales by at least month of birth, and one must have more information than is available on the shape of the force of mortality during the first year of life. Accordingly, and assuming that the majority of the issue age 0 sales are soon after birth, the age-last-birthday rates for issue age 0 are 75% of the age 0 rates and 25% of the age 1 rates from the age-nearest table.

The age-last-birthday tables are published with the age nearest, and clearly identified in the headings as such.

# 8 Female smokers

There is one subset of the data that has many surprises: female smokers, especially at older ages. The ratio of smoker to non-smoker mortality is much higher at most ages than was seen in CIA9704. At the very old ages, there are many cases of female smoker raw mortality rates exceeding those of male smokers. There seems to have been no mortality improvement for female smokers over the last several years.

Table 18 shows the raw mortality rates for males and females, and the standard deviations associated with each. The female rate exceeds the male rate in nine of the 16 ages shown. In comparison for non-smokers at the same ages, only one is greater for females than males, and that is within 5% of the male rate.

| Table 18. Raw smoker mortality rates for ultimate data by amount | | | | |
|---|---|---|---|---|
| **Attained Age** | **Mortality Rates** | | **Standard Deviations** | |
| | **Male** | **Female** | **Male** | **Female** |
| 85 | 0.114 | 0.122 | 0.010 | 0.014 |
| 86 | 0.116 | 0.098 | 0.012 | 0.015 |
| 87 | 0.131 | 0.126 | 0.014 | 0.018 |
| 88 | 0.129 | 0.140 | 0.017 | 0.023 |
| 89 | 0.184 | 0.223 | 0.021 | 0.027 |
| 90 | 0.165 | 0.179 | 0.025 | 0.026 |
| 91 | 0.211 | 0.249 | 0.033 | 0.030 |
| 92 | 0.266 | 0.169 | 0.042 | 0.024 |
| 93 | 0.203 | 0.152 | 0.054 | 0.034 |
| 94 | 0.157 | 0.302 | 0.071 | 0.060 |
| 95 | 0.142 | 0.183 | 0.097 | 0.046 |
| 96 | 0.177 | 0.206 | 0.136 | 0.064 |
| 97 | 0.634 | 0.313 | 0.179 | 0.074 |
| 98 | 0.223 | 0.353 | 0.095 | 0.094 |
| 99 | 0.274 | 0.200 | 0.116 | 0.082 |
| 100 | 0.194 | 0.084 | 0.099 | 0.120 |
| 85–93 | 0.142 | 0.144 | 0.006 | 0.007 |
| 94–100 | 0.230 | 0.257 | 0.050 | 0.030 |
| 85–100 | 0.145 | 0.151 | 0.006 | 0.007 |

It is tempting to declare the high mortality for female smokers a statistical fluctuation which should be ignored, but there seems to be too much data to ignore.

For example, for smokers ultimate attained ages 85–95 in the highest three size bands there are 26 male deaths but 35 female deaths on 250 years of exposure for males and only 172 for females.

Table 19 shows that the mortality rate actually increases with each size band for female smokers. This is highly unusual. (The male mortality rates have a downward trend, but it is far from monotonic.)

**Table 19. Raw smoker mortality rates for ultimate ages 85–95 by size band, by amount**

| Size Band | Mortality Rates | | Standard Deviations | |
|---|---|---|---|---|
| | Male | Female | Male | Female |
| 1 | 0.139 | 0.123 | 0.010 | 0.009 |
| 2 | 0.153 | 0.128 | 0.008 | 0.008 |
| 3 | 0.144 | 0.133 | 0.027 | 0.034 |
| 4 | 0.152 | 0.135 | 0.037 | 0.040 |
| 5 | 0.111 | 0.181 | 0.086 | 0.126 |
| 6 | 0.138 | 0.187 | 0.113 | 0.133 |
| 7 | 0.050 | 0.254 | 0.224 | 0.146 |
| All | 0.142 | 0.148 | 0.016 | 0.020 |

The final table for adult smokers has a diagonal section centred around attained age 92 and continuing for about three or four ages on either side where female rates are higher than the corresponding male rates. Because the graduated rates seem to accurately reflect the experience, there has been no attempt to “correct” the anomaly.

# 9 Preferred classes and COVID-19

The CIA mortality study includes an indication of preferred classes when applicable. It would be desirable to distinguish preferred classes in the new table in addition to smoking status. However, doing so is not practical because the preferred data is still too recent to allow for an ultimate table and because the definitions of preferred classes are not standardized across all companies. There is also the pragmatic concern that breaking the data into more subsets will result in less credibility for the whole exercise.

Accordingly, the new table does not distinguish by preferred classes.

CIA2014 was constructed using data in which there were no deaths due to COVID-19. The CIA will need to monitor mortality experience more closely than usual over the next few years to determine whether there is any long-term impact on mortality from COVID-19. It is already known that there has been an increase in deaths due to COVID-19 and a decrease in deaths due to some other causes. It is possible that we may see significant decreases in mortality rates for a time because some of the more vulnerable insureds succumbed to COVID-19 and left behind a group of insureds who are, on average, in slightly more robust health than before the pandemic struck. There is currently no evidence to suggest that CIA2014 will not be appropriate in the years ahead, after an appropriate adjustment for mortality improvement.

# 10 Conclusion

Mortality experience has changed markedly since CIA9704 was published. The new table, CIA2014, appears to reflect appropriately the experience of the CIA mortality study running from anniversaries in 2009 to 2019. The table is constructed as of January 1, 2014.

Although CIA2014 fits the intercompany experience well, it may not be directly suitable for any one company. It is good practice for the actuary to assess the company's experience, its definitions for risk classes, and its product designs to determine what adjustment, if any, is needed.

CIA2014, unlike tables published earlier, includes a set of rates for the "unknown" class, although for ultimate only. This was done for completeness. It is likely that a variety of company practices underlie the "unknown." It is possible that this class will be of practical use. If select rates for the "unknown" class are needed, it is suggested that the "all" rates be used instead. The published tables include the "all" select rates in the "unknown" tables, noted as such.

CIA2014 is available for download and in AXIS format.

## 10.1 Cautions

Although CIA2014 appears to fit the intercompany experience well, actuaries are advised to exercise the following cautions.

CIA2014 may not fit the experience of a particular company as well as it fits the intercompany data.

Rates for attained ages over 95 are extrapolated and not directly supported by experience. On the other hand, experience suggests that most companies understate deaths at these high ages due to a lack of reporting of deaths.

Rates under issue age 20 are not supported by an abundance of data, and the smoker classifications may not be consistent across companies.

The rates at very high ages for female smokers are much closer to male smoker rates than was observed in prior history, although the differences are adequately supported by experience of the last 10 years.

## 10.2 Summary of differences between CIA9704 and CIA2014

The following table outlines the differences in data, characteristics, and method.

| Criterion | CIA9704 | CIA2014 |
|---|---|---|
| Underlying data | CIA study, policy years 1997–2004, and population data at advanced ages. Amounts under $100 and over $50 million excluded | CIA study, policy years 2009–2019. Renewable term (other than YRT) policies excluded after first renewal |
| Mortality improvement | None | MI-2017 |
| Base date | Not stated (calculated to be 2000 09 20) | 2014 01 01 |
| Risk classes | Combined, smoker and non-smoker | Smoker, non-smoker, unknown (ultimate only), and combined |
| Select period | 15 years | 20 years |
| Maximum issue age | 80 as published. Some informal extensions exist | 90 |
| Maximum attained age | 120 | 115 |
| Handling of fluctuations due to large amounts | Experience in first policy year rejected for males age 22, 25, 63, and 80, and for females 16, 18, 19, 20, 32, and 61 as outliers | Face amounts of $1 million or more replaced by $1.5 million. One record for $6 million and two for $2.5 million rejected |
| Graduation of ultimate | Whittaker–Henderson to age 80. Rates over age 60 replaced by a Makeham curve fit to graduated values for 60–80 and extended to 99 | Whittaker–Henderson on ages 36–100 |

| Criterion | CIA9704 | CIA2014 |
|---|---|---|
| Graduation of select | Parametric graduation | Whittaker–Henderson in two dimensions. Extended from age 80 to 90 by judgement |
| Juvenile ages | Method not stated. Smoker and non-smoker start at issue age 16 | Separate graduation for ages 2–40. Graduated rates used to age 31. Interpolation for ultimate ages 32–39 by cubic |
| Oldest ages | Converge linearly from graduated rates calculated on CIA data at age 80 to Canadian life tables at age 90 and on Canadian life tables thereafter | Kannisto curve fit to ages 85–95 used for ages 105–114. Interpolation for ages 96–104 by log cubic |
| Final adjustment | From -2% to +6% depending on risk class | None |

# 11 Alternative methods

Many would argue that a mortality table should be constructed from data with no modifications. The construction presented above does not agree. There are modifications to remove apparent anomalies, to limit the fluctuation by size in the highest size band, and to reflect mortality improvement relative to the start of 2014. The reason for the modification is that the table is intended for use regarding future events and not simply to record history. Adjustments which make the table more appropriate for use in real-life actuarial applications are desirable.

There remains a significant factor which can lead the table to be less appropriate than it might be, and that relates to the distribution by size. The average size tends to vary by issue age, initially increasing from the juvenile ages to the adult ages, and then decreasing to the oldest ages. The average size also tends to decrease with increasing policy year; the average size of ultimate experience is much less than for select. The variations could present a problem because the A/E ratios tend to decrease markedly with increasing size.

Consider the example of a group of male non-smokers aged 50 now buying insurance. The underlying experience, after the modifications mentioned above, has an average size of

$481k in the first policy year. For issue age 50, in the 11th policy year, the average size is $233k; for the ultimate at attained age 70 it is $96k. If the average size being sold now is $500k, then an actuary would want mortality rates in the future for this cohort to be consistent with $500k in all future years. An actuary cannot make a simple modification to the table to reflect the size for all future years because the adjustment would need to vary by policy year.

There are two possible solutions to the problem, presented in the next two subsections. These solutions are presented here not out of a belief that they are superior but to stimulate thinking on how to approach the problem. There may be a creative solution that most would support and which would yield tables of greater practical use.

## 11.1 Standardized size distribution

The approach in this alternative is suggested by a technique often used by demographers. They are called upon to compare the mortality in different countries. The combined mortality rate per thousand of population is available, but it can be misleading because countries with a lower average age will tend to have lower combined mortality rates. Demographers are able to make a meaningful comparison by calculating age-adjusted mortality rates. That is, they apply the age-specific mortality rates of the subject countries to a standard population. They still have a single number for each country, but by this technique the complicating factor of differences in age distribution has been eliminated.

The CIA mortality experience has a similar problem. As mentioned above, the distribution by size (rather than age) can vary significantly. The correction is to make a standard distribution by size band and apply that same distribution to all age-policy year cells. Distributions are calculated using the modified data, separately for each risk class, for all ages in the dataset, both select and ultimate. The calculated distributions are shown in Table 20. The “All” classification could be considered redundant because the data for all smoking classifications combined could be calculated from the sum of the three separate classifications. In fact, the modification was done for each of the eight risk classes independently, and the redundancy was ignored.

| Table 20. Distribution of amount by size band. Modified data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Size Band | Amount Range | Smoker | | Non-smoker | | Unknown | | All | |
| | | Male | Female | Male | Female | Male | Female | Male | Female |
| 1 | (0–10k) | 0.0010 | 0.0018 | 0.0002 | 0.0003 | 0.0731 | 0.1048 | 0.0026 | 0.0029 |
| 2 | (10–50k) | 0.0489 | 0.0986 | 0.0139 | 0.0245 | 0.3865 | 0.4660 | 0.0294 | 0.0404 |
| 3 | (50–100k) | 0.0772 | 0.1341 | 0.0332 | 0.0499 | 0.2489 | 0.2401 | 0.0444 | 0.0606 |
| 4 | (100–250k) | 0.2264 | 0.2951 | 0.1533 | 0.2109 | 0.1907 | 0.1282 | 0.1615 | 0.2153 |
| 5 | (250–500k) | 0.2175 | 0.2288 | 0.1897 | 0.2440 | 0.0528 | 0.0278 | 0.1880 | 0.2378 |
| 6 | (500k–1m) | 0.2029 | 0.1469 | 0.2452 | 0.2524 | 0.0254 | 0.0164 | 0.2340 | 0.2390 |
| 7 | 1m+ | 0.2261 | 0.0946 | 0.3645 | 0.2180 | 0.0225 | 0.0165 | 0.3400 | 0.2040 |

| Table 21. Size band adjustment for Mns issue age 45 policy year 6 (amounts in thousands) | | | | | |
|---|---|---|---|---|---|
| Size Band | Standard Distrib | Before | | After | |
| | | Amount | Rate | Amount | Rate |
| 1 | 0.0002 | 611 | 0.00944 | 2,884 | 0.00944 |
| 2 | 0.0139 | 26,484 | 0.00086 | 221,024 | 0.00086 |
| 3 | 0.0332 | 95,572 | 0.00159 | 528,002 | 0.00159 |
| 4 | 0.1533 | 1,286,486 | 0.00102 | 2,440,876 | 0.00102 |
| 5 | 0.1897 | 3,077,218 | 0.00068 | 3,021,741 | 0.00068 |
| 6 | 0.2452 | 4,364,982 | 0.00128 | 3,905,582 | 0.00128 |
| 7 | 0.3645 | 7,073,850 | 0.00105 | 5,805,093 | 0.00105 |
| Tot/Avg | 1 | 15,925,202 | 0.00104 | 15,925,202 | 0.00105 |

Table 21 gives an example of the calculation for a particular age-duration cell, in this case for Mns issue age 45, sixth policy year. The total amount exposed is redistributed in proportion to the numbers in the column "Standard Distrib." The mortality rates in the "Before" section are applied to the amounts in the "After" section to determine the adjusted death claim amounts. The weighted average mortality rate changes slightly. A similar calculation is done in each age-policy year cell.

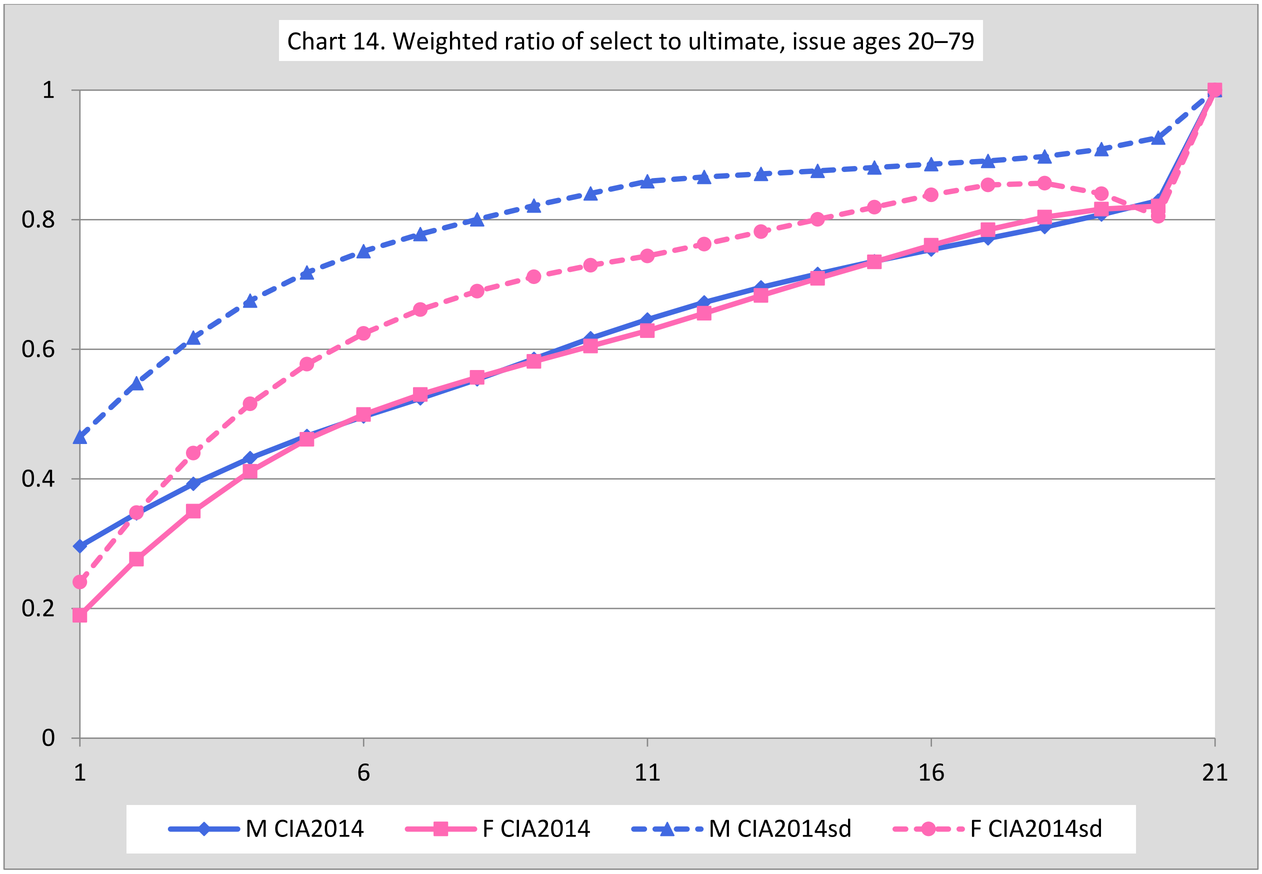
**Table 22. Size band adjustment for Fsm issue age 76 policy year 11 (amounts in thousands)**

| Size Band | Standard Distrib | Before | | After | |
|---|---|---|---|---|---|
| | | Amount | Rate | Amount | Rate |
| 1 | 0.0018 | 0 | - | 0 | - |
| 2 | 0.0986 | 196 | 0.05263 | 161 | 0.05263 |
| 3 | 0.1341 | 50 | 0.00000 | 218 | 0.00000 |
| 4 | 0.2951 | 800 | 0.24166 | 480 | 0.24166 |
| 5 | 0.2288 | 186 | 0.00000 | 372 | 0.00000 |
| 6 | 0.1469 | 0 | - | 0 | - |
| 7 | 0.0946 | 0 | - | 0 | - |
| Tot/Avg | 1 | 1,231 | 0.16537 | 1,231 | 0.10110 |

However, the calculation as shown above will not always work. The mortality rate cannot be calculated for a band that has no exposure. In that case, the calculation is modified so that empty bands are ignored, and the exposure is redistributed over non-empty bands only. This is shown in Table 22 for Fsm issue age 76, 11th policy year. The average mortality rate decreases substantially because in the original distribution the band with the highest mortality rate was over-weighted compared to the standard.

The modified data is now used to calculate a table with the method and parameters exactly as described for CIA2014. This alternate table, developed from data with a standardized distribution, is referred to as CIA2014sd.

One of the concerns with CIA2014 is the discontinuity in mortality rates from the end of the select period to the ultimate rates. With CIA2014sd one would expect the discontinuity to be smaller and the ratio for the first policy to be higher. The reason for the change is that there is considerably more weight in the ultimate years placed on the higher size bands, for which the mortality rate tends to be less. Chart 14 illustrates the differences in select/ultimate ratios.




The pattern for males appears to be improved, but the pattern looks strange for females at the higher policy years.

Table 23 compares some net level premium rates of CIA2014sd to those of CIA2014. (The values for CIA2014 are shown in Table 17. The calculations on CIA2014sd are the same except for the mortality table.) We see that there is little difference overall, with CIA2014sd being a little lower, particularly in the ultimate, as evidenced by the whole life premiums, but there can be significant changes within the table at various ages.

**Table 23. Ratio of values on CIA2014sd to those on CIA2014**

| Issue Age | 10-Yr Term Net Level Premium | | | | Whole Life Net Level Premium | | | |
|---|---|---|---|---|---|---|---|---|
| | Mns | Fns | Msm | Fsm | Mns | Fns | Msm | Fsm |
| 30 | 102% | 99% | 97% | 92% | 97% | 100% | 98% | 98% |
| 40 | 96% | 97% | 96% | 109% | 98% | 100% | 98% | 98% |
| 50 | 106% | 105% | 109% | 106% | 99% | 99% | 99% | 98% |
| 60 | 113% | 110% | 103% | 96% | 100% | 98% | 99% | 98% |
| 70 | 108% | 78% | 100% | 95% | 100% | 96% | 99% | 98% |

The purpose of this subsection is to illustrate another approach to getting a more homogeneous dataset. That is not to imply that CIA2014sd is superior to CIA2014.

However, when looking into the detailed rates, some valid concerns about CIA2014sd arise. There are many more inversions than are found in CIA2014. The method of size-adjusting mortality rates may be causing anomalies.

At both young and old extremes of the data there are many cells with no exposure in some bands, particularly the higher bands. It is far from certain that the resulting modification gives a clearer picture. Where there is a small amount of exposure in the higher bands, the modification could amplify statistical fluctuations. Table 24 shows another type of strange case. The problem is not at the higher bands, but in a band with little exposure but a high claim rate; a single claim is multiplied over 10 times.

**Table 24. Size band adjustment for Msm issue age 36 policy year 1 (amounts in thousands)**

| Size Band | Standard Distrib | Before | | After | |
|---|---|---|---|---|---|
| | | Amount | Rate | Amount | Rate |
| 1 | 0.0010 | 115 | 0.00000 | 3,573 | 0.00000 |
| 2 | 0.0489 | 10,523 | 0.00220 | 173,284 | 0.00220 |
| 3 | 0.0772 | 30,217 | 0.00327 | 273,199 | 0.00327 |
| 4 | 0.2264 | 364,517 | 0.00000 | 801,429 | 0.00000 |
| 5 | 0.2175 | 763,939 | 0.00000 | 770,110 | 0.00000 |
| 6 | 0.2029 | 1,052,788 | 0.00000 | 718,223 | 0.00000 |
| 7 | 0.2261 | 1,318,163 | 0.00000 | 800,443 | 0.00000 |
| Tot/Avg | 1 | 3,540,261 | 0.00003 | 3,540,261 | 0.00036 |

There are many odd cells within the data which will have unexpected adjustments. This method may not be safe to use unless there is some constraint on how large the adjustments can be.

It is good that the table can be constructed from a more homogeneous dataset, but it is difficult to see how to calibrate the table to a company's experience which is not as homogeneous. This alternative is worth studying but it is not yet ready for practical use.

## 11.2 Size adjustment

It is widely known that mortality tends to decrease with increasing size. Until CPM2014 was developed, no table explicitly recognized the impact of size in table construction. A set of size adjustment factors was published along with the table. Something similar could be done with CIA2014.

Using CIA2014, the A/E ratio is calculated for data in each band and for each risk class. These ratios are then divided by the ratio for Band 4 in each risk class. The resulting ratios are shown in Table 25, and the standard deviations of the ratios in Table 26. Table 25 shows some anomalies: Msm and Fsm Band 1 is lower than the corresponding Band 2, and Munk Bands 5–7 trend in the wrong direction. The anomalies are not serious because the table is being used only for proof of concept.

**Table 25. Size adjustment factors relative to band 4**

| Band | Msm | Fsm | Mns | Fns | Munk | Funk | Mall | Fall |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.933 | 0.961 | 1.193 | 1.194 | 1.231 | 1.303 | 1.192 | 1.253 |
| 2 | 1.095 | 1.102 | 1.147 | 1.130 | 1.210 | 1.249 | 1.224 | 1.245 |
| 3 | 1.023 | 1.059 | 1.067 | 1.069 | 1.075 | 1.124 | 1.095 | 1.108 |
| 4 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 5 | 0.951 | 0.899 | 0.935 | 0.947 | 0.834 | 1.382 | 0.926 | 0.957 |
| 6 | 0.916 | 1.072 | 0.901 | 0.946 | 0.882 | 0.863 | 0.889 | 0.960 |
| 7 | 0.827 | 0.899 | 0.863 | 0.832 | 0.876 | 0.663 | 0.841 | 0.842 |

**Table 26. Standard deviation in size adjustment factors**

| Band | Msm | Fsm | Mns | Fns | Munk | Funk | Mall | Fall |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.014 | 0.014 | 0.016 | 0.014 | 0.003 | 0.004 | 0.003 | 0.004 |
| 2 | 0.007 | 0.007 | 0.005 | 0.005 | 0.004 | 0.007 | 0.003 | 0.004 |
| 3 | 0.012 | 0.015 | 0.008 | 0.009 | 0.010 | 0.024 | 0.005 | 0.008 |
| 4 | 0.014 | 0.020 | 0.007 | 0.009 | 0.016 | 0.045 | 0.006 | 0.008 |
| 5 | 0.030 | 0.047 | 0.013 | 0.018 | 0.041 | 0.130 | 0.011 | 0.016 |
| 6 | 0.047 | 0.083 | 0.017 | 0.027 | 0.076 | 0.233 | 0.015 | 0.025 |
| 7 | 0.067 | 0.121 | 0.022 | 0.040 | 0.112 | 0.411 | 0.020 | 0.037 |

These ratios can be used to modify the deaths on each record to be consistent with experience for Band 4. That is, the actual claims are divided by the appropriate factor above so that the amount of death claims is approximately consistent with what would be experienced in Band 4 as opposed to the actual band. The resulting modified data is then taken as representative of all experience being in Band 4. Because the majority of exposure in the ultimate period averaged lower than Band 4, one would expect the ultimate rates to be lower than in CIA2014. One would expect higher rates for male non-smokers in the select period, but otherwise not much change for select.

Using the data modified to Band 4, another table was constructed with the same method as CIA2014 and all the same parameters. This table is referred to as CIA2014b4.

Table 27 is similar to Table 10, except that it uses CIA2014b4 as the base table rather than CIA2014 to calculate ultimate A/E. The underlying data is the same as for Table 10. The size adjustment factors of Table 24 are used in calculating the expected mortality for each size band. The resulting A/E are very close to those of Table 10, although in most cases the values of Table 10 are closer to 100% than the corresponding values of Table 27. It is remarkable that the values of Table 27 are as close to 100% as they are because CIA2014b4 was not calibrated on the same modified data as was used for CIA2014.

**Table 27. A/E claims on ultimate of CIA2014b4 with improvement on MI-2017. Age ranges are of attained ages**

| | 0–15 | 16–39 | 40–93 | 94–100 | 21–100 | 0–100 |
|---|---|---|---|---|---|---|
| Msm | | 98.9% | 100.0% | 87.5% | 99.9% | 99.9% |
| Fsm | | 97.7% | 99.7% | 97.9% | 99.7% | 99.6% |
| Mns | | 100.7% | 100.1% | 96.3% | 100.0% | 100.0% |
| Fns | | 110.3% | 99.9% | 101.8% | 100.2% | 100.2% |
| Munk | 97.0% | 96.8% | 100.1% | 87.9% | 99.4% | 99.4% |
| Funk | 95.4% | 93.2% | 100.1% | 91.7% | 99.3% | 99.2% |
| Mall | 95.6% | 100.1% | 100.5% | 90.6% | 100.1% | 100.1% |
| Fall | 99.1% | 102.7% | 100.3% | 96.7% | 100.2% | 100.1% |

Table 28 is likewise similar to Table 11. In these cases, the original data is used for actual and expected. In most cases the values of Table 28 are closer to 100% than the corresponding values of Table 11. That implies that CIA2014b4 with size adjustment factors fits the data better than CIA2014.

**Table 28. A/E claims on ultimate of CIA2014b4 with improvement on MI-2017. Original data. Age ranges are of attained ages**

| | 0–15 | 16–39 | 40–93 | 94–100 | 25–100 | 0–100 |
|---|---|---|---|---|---|---|
| Msm | | 96.9% | 99.0% | 85.6% | 98.8% | 98.8% |
| Fsm | | 96.5% | 100.5% | 114.7% | 100.6% | 100.5% |
| Mns | | 100.1% | 99.7% | 107.4% | 99.9% | 100.0% |
| Fns | | 106.3% | 99.5% | 100.1% | 99.5% | 99.6% |
| Munk | 93.6% | 94.3% | 100.0% | 89.1% | 99.3% | 99.3% |
| Funk | 92.9% | 91.8% | 100.0% | 91.6% | 99.1% | 99.0% |
| Mall | 92.3% | 98.2% | 100.1% | 95.9% | 99.9% | 99.9% |
| Fall | 95.8% | 100.4% | 100.2% | 96.7% | 99.9% | 99.9% |

Table 29 is comparable to Table 15, showing A/E on select original data. As with Table 28, in most cases the values of Table 29 are closer to 100% than those of Table 15.

**Table 29. A/E ratios on CIA2014b4. Age groups are of issue ages. First 20 policy years only. Original data**

| | 0–19 | 20–29 | 30–39 | 40–70 | 25–80 | 0–90 |
|---|---|---|---|---|---|---|
| Msm | 94.6% | 102.7% | 95.5% | 98.7% | 98.3% | 98.3% |
| Fsm | 97.4% | 93.0% | 99.3% | 100.5% | 101.2% | 101.0% |
| Mns | 102.6% | 104.5% | 101.1% | 99.0% | 98.9% | 99.3% |
| Fns | 104.8% | 97.4% | 95.2% | 98.8% | 97.6% | 97.8% |
| Mall | 94.9% | 102.1% | 100.5% | 99.0% | 99.1% | 99.3% |
| Fall | 95.4% | 97.2% | 96.0% | 99.0% | 98.4% | 98.6% |

It seems reasonable to conclude that this alternative holds considerable promise. It warrants further study.

## 11.3 Parametric graduation

Some might wonder why the method used for the last three CIA life insurance tables was not used for the select period. (See, for example, pp. 5–6 of CIA document 210028.) That method may have suited the data used in the earlier tasks, but it does not fit the current data well.

In testing parametric graduation, there are some tweaks to the method. The range of issue ages used is 16–85 rather than 15–80. The select period is extended to 20 years. The least-squares expression for $r(x)$ to be minimized is weighted rather than unweighted. There is probably a transcription error in the expression to be minimized for $G(t)$, which is corrected. The expressions used are:

$$\sum_{x=16}^{85} E_{[x]}(r(x) - \hat{r}(x))^2$$

$$\sum_{x=16}^{85}\sum_{t=0}^{19} E_{[x-t]+t}\left[q_x^{CIA2014}\left(r(x) + G(t)(1 - r(x))\right) - q_{[x-t]+t}^{raw}\right]^2$$

Although the parameters are found that minimize the expressions, the A/E ratios are not brought close to 100%. Table 30 compares A/E for CIA2014 with the table calculated using parametric graduation for Mall, the largest risk class. CIA2014 is much closer to 100%, not just for all ages and durations combined but also for almost every issue age and duration grouping.

**Table 30. A/E ratios for CIA2014 and a table by parametric graduation for Mall**

| CIA2014 | | | | | Issue Age | Alternative Table | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Durations | | | | | | Durations | | | | |
| 0–4 | 5–9 | 10–14 | 15–19 | 0–19 | | 0–4 | 5–9 | 10–14 | 15–19 | 0–19 |
| 96.1% | 97.7% | 97.6% | 105.1% | 98.8% | 16–35 | 106.6% | 115.0% | 101.8% | 97.5% | 105.9% |
| 101.1% | 101.8% | 99.0% | 98.1% | 100.3% | 36–50 | 122.6% | 116.1% | 99.1% | 86.9% | 106.6% |
| 99.6% | 99.1% | 101.0% | 97.2% | 99.0% | 51–65 | 105.8% | 106.0% | 100.5% | 85.4% | 98.7% |
| 95.8% | 99.0% | 107.2% | 104.3% | 103.0% | 66–85 | 87.3% | 97.6% | 106.6% | 94.9% | 97.5% |
| 99.5% | 100.1% | 100.7% | 99.6% | 99.9% | 16–85 | 111.4% | 110.9% | 101.0% | 88.8% | 102.6% |

This alternative is not recommended.

# 12 Estimating accuracy

The goal of table construction is to determine the true underlying mortality table of which the observed experience is a single case subject to statistical fluctuation. It is not an achievable goal because we cannot know that true underlying table regardless of how much data we have or how we construct the table. Because we need to use all the data that we have to get the closest estimate, we have no external benchmark to guide on the degree of accuracy that we have achieved. (Some parametric graduation methods allow for confidence intervals to be determined for the parameters, but the method used here does not.)

There is a way to get a sense of the accuracy, even if not a precise measure. That is to simulate sets of data comparable to that actually used and then construct a mortality table using the method of CIA2014 on each one.

The simulation assumes that CIA2014 with a set of size adjustment factors (similar to the factors in Table 25 but smoothed some) is the true underlying mortality table, and that deaths are binomially distributed within each risk class/issue age/policy year/size band cell. Each actual cell is represented by one to three subcells which maintain the number of policies and the sum of the amounts of the policies. The sum of squares of the amounts is also maintained, if feasible, within the constraints of the algorithm. After developing one portfolio of cells and subcells to represent the actual data, 1,000 sets of death claims were generated randomly. For each set of death claims, a mortality table was developed by using all the same methods and parameters as for CIA2014.

There was one exception on the parameters. If a negative mortality rate was produced by the graduation, the graduation parameters were adjusted to keep all rates positive. Some adjustment was needed for two of 1,000 sets. The simulation does not provide for any interventions other than the one mentioned in this paragraph.

Table 31 shows the ratio of the standard deviation in mortality rates across the 1,000 simulated tables to the mean of those mortality rates for males, combining all smoking classes ("Mall"). The left part of Table 31 considers the rates of the tables constructed; the right part considers the simulated raw mortality rates.

**Table 31. Ratio of standard deviation to mean for simulated mortality rates for Mall**

| Issue Age | Graduated Rates | | | | | Simulated Raw Rates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Policy Year | | | | | Policy Year | | | | |
| | 1 | 6 | 11 | 16 | Ult | 1 | 6 | 11 | 16 | Ult |
| 20 | 0.072 | 0.050 | 0.049 | 0.067 | 0.067 | 0.855 | 0.839 | 0.867 | 0.715 | 0.147 |
| 30 | 0.086 | 0.044 | 0.056 | 0.042 | 0.029 | 0.405 | 0.372 | 0.429 | 0.365 | 0.067 |
| 40 | 0.077 | 0.040 | 0.033 | 0.029 | 0.016 | 0.368 | 0.251 | 0.299 | 0.262 | 0.038 |
| 50 | 0.067 | 0.030 | 0.025 | 0.024 | 0.014 | 0.305 | 0.222 | 0.301 | 0.240 | 0.031 |
| 60 | 0.067 | 0.029 | 0.026 | 0.024 | 0.012 | 0.368 | 0.267 | 0.329 | 0.246 | 0.029 |
| 70 | 0.080 | 0.037 | 0.031 | 0.026 | 0.012 | 0.660 | 0.497 | 0.401 | 0.264 | 0.030 |

The graduated rates show much less volatility than the raw rates, particularly for the 11th policy year. The first policy year is not quite as good because any two-dimensional graduation method will be less reliable at the edges, and there is no way to avoid the first policy year being an edge. The improvement in volatility of graduated compared to raw is less for ultimate than for the select period, but that is not a big concern because the volatility for ultimate is acceptably low.

**Table 32. Ratio of standard deviation to mean for simulated mortality rates for Msm**

| Issue Age | Graduated Rates | | | | | Simulated Raw Rates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Policy Year | | | | | Policy Year | | | | |
| | 1 | 6 | 11 | 16 | Ult | 1 | 6 | 11 | 16 | Ult |
| 20 | 0.097 | 0.068 | 0.071 | 0.130 | 0.118 | 1.931 | 1.547 | 1.661 | 1.149 | 0.286 |
| 30 | 0.140 | 0.076 | 0.100 | 0.074 | 0.051 | 0.768 | 0.684 | 0.844 | 0.666 | 0.125 |
| 40 | 0.134 | 0.072 | 0.056 | 0.043 | 0.029 | 0.761 | 0.548 | 0.635 | 0.450 | 0.069 |
| 50 | 0.109 | 0.050 | 0.043 | 0.038 | 0.027 | 0.640 | 0.472 | 0.632 | 0.455 | 0.066 |
| 60 | 0.114 | 0.049 | 0.042 | 0.039 | 0.029 | 0.820 | 0.622 | 0.729 | 0.370 | 0.080 |
| 70 | 0.119 | 0.052 | 0.045 | 0.042 | 0.045 | 1.867 | 0.879 | 1.415 | 1.002 | 0.122 |

Table 32 is comparable to Table 31 but for male smokers ("Msm"). The amount of exposure for Msm is substantially less than for Mall, and consequently the volatility is higher. With the ratio of standard deviation to mean in the range of 5% for most of the table, it can be considered acceptable, but not as solid as one might like.

This exercise serves two purposes. First, it gives us confidence that the method handles fluctuation in the data and results in mortality rates that are within a sufficiently narrow range. Second, it reminds us that the rates of any mortality table are estimates that are subject to statistical fluctuation.

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# 14 Appendix: Applying mortality improvement

Recognizing that a standard formula for applying mortality improvement is hard to find, the CPM report on p. 9 has the following definition.

$I_x^y$ means the improvement rate in mortality for persons aged *x* nearest birthday at the start of calendar year *y*-1 to those aged *x* at the start of calendar year *y*. In this case, *x* is constant through the one-year period and *y* is defined at the end of the period.

This definition then can be applied as follows:

$$q_{[x]+t}^{y} = q_{[x]+t}^{y-1}(1 - I_x^y)$$

It can further be generalized to

$$q_{[x]+t}^{y-1+a} = q_{[x]+t}^{y-1}(1 - I_x^y)^a, \text{where } 0 \leq a \leq 1$$

For example, if one wants the mortality rate applicable to the middle of 2015 for a male non-smoker, issue age 50, using CIA2014 with MI-2017, then the rate would be calculated as

$q_{[50]}^{2015.5} = 0.000489\ (1 - 0.0203)(1 - 0.0197)^{0.5} = 0.000474$

The calculation uses the mortality improvement rates for male age 50 for years 2015 and 2016. Note that the improvement rate for 2014 is not used because the base of CIA2014 is the beginning of 2014.

The next mortality rate along the same cohort is

$q_{[50]+1}^{2016.5} = 0.000609\ (1 - 0.0202)(1 - 0.0196)(1 - 0.0189)^{0.5} = 0.000579$

MI-2017 is used in this work consistently with the above definition and examples.

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