Demographic Research a free, expedited, online journal
of peer-reviewed research and commentary
in the population sciences published by the
Max Planck Institute for Demographic Research
Konrad-Zuse Str. 1, D-18057 Rostock · GERMANY
www.demographic-research.org

DEMOGRAPHIC RESEARCH

VOLUME 24, ARTICLE 25, PAGES 611-632
PUBLISHED 21 APRIL 2011
http://www.demographic-research.org/Volumes/Vol24/25/
DOI: 10.4054/DemRes.2011.24.25

Research Article

On the correspondence between CAL and lagged cohort life expectancy

Michel Guillot

Hyun Sik Kim

Table of Contents

Demographic Research: Volume 24, Article 25
Research Article

On the correspondence between CAL and lagged cohort life expectancy

Michel Guillot[1]

Hyun Sik Kim[2]

Abstract

It has been established that under certain mortality assumptions, the current value of the Cross-sectional Average length of Life (CAL) is equal to the life expectancy for the cohort currently reaching its life expectancy. This correspondence is important, because the life expectancy for the cohort currently reaching its life expectancy, or lagged cohort life expectancy (LCLE), has been discussed in the tempo literature as a summary mortality measure of substantive interest. In this paper, we build on previous work by evaluating the extent to which the correspondence holds in actual populations. We also discuss the implications of the CAL-LCLE correspondence (or lack thereof) for using CAL as a measure of cohort life expectancy, and for understanding the connection between CAL, LCLE, and underlying period mortality conditions.

[1] Population Studies Center, University of Pennsylvania, 3718 Locust Walk, Philadelphia PA 19104, USA. E-mail: miguillo@sas.wisc.edu.
[2] Center for Demography and Ecology, University of Wisconsin-Madison, 1180 Observatory Drive, Madison WI 53706, USA. E-mail: hskim@ssc.wisc.edu.

1. Introduction

In recent years several alternative summary measures of mortality have emerged in the context of the debate on "tempo effects." The existence of tempo effects in mortality is still a controversial issue. Nonetheless this debate has generated a healthy discussion about various ways of summarizing a population's mortality experience.

One measure that has been discussed in the context of this debate is the Cross-sectional Average length of Life (CAL). CAL's original purpose was not to address tempo effects in mortality. In fact CAL was developed prior to Bongaarts and Feeney's proposition that there are tempo effects in mortality, and it has its own interpretation aside from tempo effects. Nonetheless CAL is closely related to Bongaarts and Feeney's tempo-adjusted life expectancy. In particular, the two indicators are equal to one another when mortality follows some specific patterns.

One other finding that has emerged from the tempo debate is the fact that, under some assumptions, CAL is equal to the life expectancy for the cohort currently reaching its life expectancy. The life expectancy for the cohort currently reaching its life expectancy, or lagged cohort life expectancy (LCLE), is an interesting index in itself, as we will explain below. However it cannot be observed for the current year, because a cohort's life expectancy or mean age at death cannot be observed until the cohort is extinct, i.e., many years after the time at which that mean age at death was reached. CAL, however, can be readily calculated for the current year with no reference to the future, as long as sufficient historical mortality data are available. Therefore the existence of a precise and consistent correspondence between CAL and LCLE could justify the use of CAL as a proxy for LCLE, an unobservable yet informative quantity. Another reason for further studying the CAL-LCLE correspondence is the fact that Bongaarts and Feeney see the existence of a correspondence between CAL (or their tempo-adjusted life expectancy) and LCLE as evidence in support of their proposition that current period life expectancy overestimates life expectancy under current mortality conditions.

In this paper, after defining CAL and LCLE, we review and compare the mortality models that generate an exact or near exact correspondence between CAL and LCLE. We then examine the extent to which the correspondence holds in actual populations. Finally we discuss the implications of the CAL-LCLE correspondence (or lack thereof) for using CAL as a proxy for LCLE, and for understanding the relationship between CAL, LCLE, and underlying period mortality conditions.

2. CAL and LCLE

2.1 CAL, the Cross-sectional Average length of Life

CAL is defined as follows:

$$CAL(t) = \int_0^\infty p_c(x, t-x)dx \tag{1}$$

where $p_c(x, t\text{-}x)$ is the probability of surviving from birth to age *x* for the cohort born at time *t-x*. In a population, $p_c(x, t\text{-}x)$ corresponds to the proportion of cohort survivors for the cohort aged *x* at time *t*. Simply put, CAL is the cross-sectional sum of proportions of cohort survivors at a given time. CAL is a mortality measure that summarizes the mortality history of all cohorts present in a population at a given time. It also corresponds to the size of the "birth-standardized," or "constant-births" population, i.e., the total size of a population with a constant unit stream of births exposed to actual, changing mortality trends.

Equation (1) takes into account mortality at all ages. Like the life expectancy, CAL can also be calculated for any starting age *x*:

$$CAL_x(t) = \int_x^\infty \frac{p_c(a, t-a)}{p_c(x, t-a)} da \tag{2}$$

By involving cohort survival to age *a* conditional on survival to age *x*, CAL_x takes into account mortality rates above age *x* only.

CAL was first defined by Brouard (1986). Further developments were introduced by Guillot (1999, 2003), including equations for the relationship between CAL change and period mortality, and the population size interpretation of CAL. Guillot (2005) has also shown that the discrepancy between e_0 and CAL during a given year can be interpreted in terms of population momentum. More recently Wachter (2005) has shown that CAL is essentially a weighted average of past levels of period life expectancy.

Bongaarts and Feeney (2003) have proposed two alternative summary mortality measures, which are closely related to CAL: M_2 (also referred to as MAD), which corresponds to the mean age at death in the birth-standardized population; and M_4, a period life expectancy calculated with period age-specific deaths rates that are adjusted upwards in situations of mortality decline. If mortality follows a specific pattern of change referred to as the "proportionality assumption," CAL, MAD, and M_4 are equal to one another (Bongaarts and Feeney 2003). Under steady mortality decline, these three indicators are all lower than period life expectancy (Bongaarts 2005).

2.2 LCLE, the Lagged Cohort Life Expectancy

Each cohort that is now extinct has a known value for its life expectancy at birth:

$$e_0^C(t) = \int_0^{\infty} p_c(x,t)dx \qquad (3)$$

In closed populations cohort life expectancy is equal to the observed mean age at death for that cohort. For cohorts that are not yet extinct, their remaining mortality experience is unknown, and thus their life expectancy or mean age at death is unknown. Unless some assumption about future mortality is made, cohort life expectancy can be calculated with certainty only for cohorts that are extinct or near extinct.

The year at which a cohort born in year *c* reaches its life expectancy (or mean age at death) is $t = c + e_0^c(c)$. Year *t* is an important year for cohort *c*; it is the mean year of death for that cohort. If there was no variation in ages at death, year *t* would be the time at which all members of cohort *c* die.

Lagged cohort life expectancy, or LCLE, is simply a graphical representation of the classic cohort life expectancy. Instead of plotting cohort life expectancy against the cohort's year of birth *c*, as commonly done, cohort life expectancy is plotted against its mean year of death, or $c + e_0^c(c)$. This lag provides a useful time reference for an indicator that summarizes a mortality experience spread over many years, but centered around its mean year of death. This graphical representation of cohort life expectancy is somewhat similar to the well-known representation of the cohort TFR, often plotted against the time at which a cohort reaches its mean age at childbearing (Ryder 1980; Schoen 2004; Keilman 2006).

LCLE(t) can be interpreted as the life expectancy for the cohort reaching its life expectancy during year *t*. Evidently it is not possible to know with certainty which cohort is currently reaching its life expectancy, because that cohort has not yet completed its mortality trajectory. LCLE can only be calculated for past years, using retrospective mortality information for cohorts that are now extinct. However even if LCLE cannot be observed for the current year, the concept it represents is useful.

There can be more than one cohort currently reaching its life expectancy. Considering annual birth cohorts, this happens when a given cohort has a life expectancy that is at least one year below that of the preceding cohort. While large annual changes in period life expectancy are not uncommon, cohort life expectancy changes much more gradually. In the data we use in this paper there are only a few exceptional cases in which e_0^c changes by one year or more from one cohort to the next. For the overwhelming majority of years, there is only one value of LCLE(t) associated with each year t. (As long as $e_0^c(c)$ is a continuous function of c, there will always be at least one cohort currently reaching its life expectancy.)

2.3 Correspondence between the two indexes

The parallel between CAL and the life expectancy of an actual cohort was first drawn by Guillot (2003:47-48). However the observation that the current CAL value might correspond to the cohort life expectancy of the cohort born CAL years earlier, or that a cohort's life expectancy might correspond to the CAL value observed at the time when that cohort reaches its life expectancy, emerged as part of the debate on tempo effects. Bongaarts and Feeney (2006) observed that in Denmark, England & Wales, and Sweden, the lagged cohort mean age at death is relatively close to MAD(t) when there is no mortality below age 30. Rodriguez (2006) and Goldstein (2006) show that when cohort survival shifts linearly over time (a pattern that we describe later), there is perfect correspondence between CAL and LCLE. Finally Bongaarts (2005) simulate a Gompertz mortality model with a constant rate of improvement over time, and find a near-exact correspondence between CAL, LCLE, and M_4 over the 50-year period of their simulation.

In this paper we focus on the comparison between LCLE and CAL rather than MAD or M_4. This choice is justified by the fact that CAL and LCLE are both based on the same basic information – cohort survival probabilities, or, equivalently, cohort person-years lived – summed in two different ways: cross-sectionally for CAL; and longitudinally for LCLE. CAL is thus more amenable to mathematical manipulation when comparing it to LCLE, and a more logical choice in empirical comparisons. However given the similarity between CAL, MAD, and M_4, the regularities observed in this paper are likely to also apply to MAD and M_4.

3. Mortality models producing an exact or near exact correspondence

3.1 Linear shift pattern of mortality change

The linear shift pattern of mortality change is a pattern in which a baseline schedule of period mortality rates, $\mu(x, 0)$, is shifted every year along the age axis by a quantity r:

$$\mu(x,t) = \mu(x - rt, 0) \,. \tag{4}$$

The linear shift assumption also assumes that $\mu(x,t)=0$ for $x<rt$.

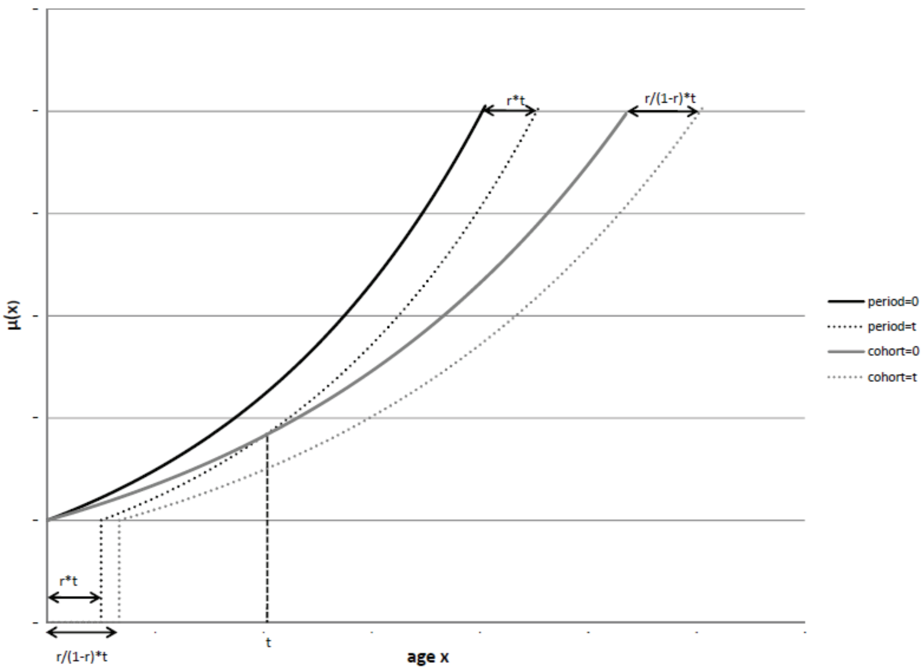
As a consequence of this shifting pattern in period mortality rates, the amount of shift for each successive cohort will be $r/(1-r)$. Starting from a baseline schedule of cohort mortality rates, $\mu^c(x, 0)$:

$$\mu^c(x,t) = \mu^C(x - \frac{r}{1-r}t, 0) \tag{5}$$

and $\mu^c(x,t)=0$ for $x<r/(1-r)\cdot t$.

Figure 1 illustrates the linear shift pattern of mortality change and the correspondence between period and cohort shifts. It is important to note here that the linear shift assumption does not make any particular parametric assumption about the age pattern of mortality.

Figure 1: Linear shift pattern of mortality change



Rodriguez (2006:99-100) has shown that, with a linear shift for periods starting at time $t=0$, CAL will follow a linear trajectory:

$$CAL(t) = e_0^P(0) + rt \tag{6}$$

where $e_0^P(0)$ is the baseline life expectancy embodied in $\mu(x,0)$. He also showed that, given a linear shift starting at time $t=0$, the cohort life expectancy at birth will also change linearly, but at a different rate $r^c = r/(1-r)$:

$$e_0^C(t) = \frac{e_0^P(0)}{1-r} + \frac{r}{1-r}t \tag{7}$$

Combining Equations (6) and (7), Rodriguez (2006) finds that:

$$CAL(t + e_0^C(t)) = e_0^C(t) \tag{8}$$

Or, alternatively, that:

$$e_0^C(t - CAL(t)) = CAL(t) \tag{9}$$

In other words under the linear shift assumption, the correspondence between CAL and LCLE is perfect. Goldstein (2006) and Wilmoth (2005) reach the same conclusion with somewhat different demonstrations. Note that this result is exact and does not involve any other assumptions besides the linear shift assumption described in Equation (4). Again no assumption is made about the shape of the mortality schedule.

We would like to note that the linear shift assumption described here generates a situation in which the period force of mortality is proportional to the concurrent age intensity of the constant-birth population, a situation which Bongaarts and Feeney's refer to as the "proportionality assumption" (Bongaarts and Feeney 2003). However the proportionality assumption is a more general assumption which does not necessarily guarantee that CAL and LCLE will agree. For example, in Bongaarts and Feeney's well-known "pill" scenario (i.e., a one-time shift in a cohort mortality happening for all cohorts at the same time), the proportionality assumption is met, but the linear shift assumption is not. There is no CAL-LCLE correspondence in this scenario. We will discuss this scenario and its implications later in the paper.

3.2 Gompertz pattern of mortality with constant log-linear decline

This is a simple model of mortality change in which age-specific mortality follows a Gompertz model with a constant rate of improvement over time:

$$\mu(x,t) = \alpha e^{\beta x} e^{-\rho t} \tag{10}$$

Using simulations Bongaarts (2005) show that when mortality follows such a pattern, CAL is approximately equal to LCLE, i.e., the correspondence holds approximately.

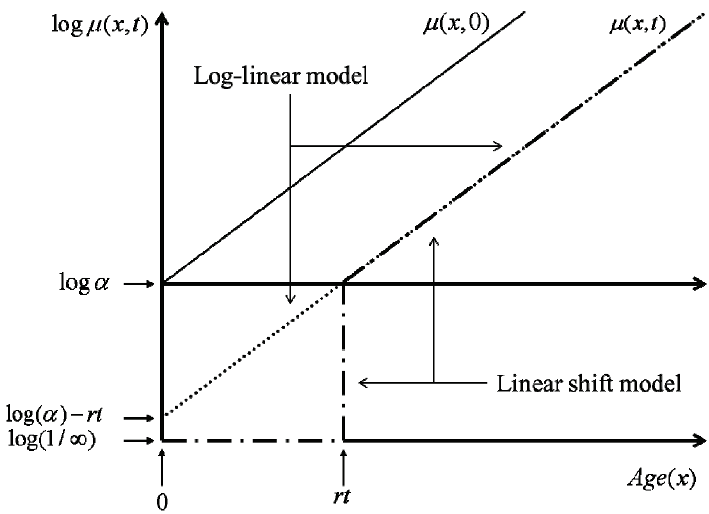
This model of mortality change is in fact quite similar to the linear shift assumption described above. Under this model, as in the linear shift model,

$$\mu(x,t) = \mu(x - rt, 0) \tag{11}$$

where $r = \rho/\beta$.

One difference, however, with the linear shift described above is that mortality at ages $x<rt$ is not equal to 0. There is *some* mortality at these ages, following Equation 10. As a result CAL does not increase exactly by an amount of ρ/β, but by a slightly smaller amount. Similarly e_0^c does not increase exactly by an amount of $\rho/(\beta-\rho)$, as one would expect under the linear shift assumption. Nonetheless the additional mortality existing under this scenario is small enough that Equations (6) and (7) can be approximated using $r = \rho/\beta$. (See Goldstein and Wachter (2006) for the details of this approximation.) Thus this Gompertz model will produce an approximate correspondence between CAL and LCLE, as Bongaarts and Feeney illustrated with their simulation. Figure 2 shows the difference between the model of mortality change described in this section, and a linear shift model in which mortality follows a Gompertz schedule.

Figure 2: Gompertz pattern of mortality with log-linear decline, and its correspondence with the linear shift pattern



An interesting feature of these two models is that they produce a linear change in both CAL and LCLE, either exactly in the case of the linear shift assumption, or approximately in the case of the Gompertz model with constant log-linear decline.

4. Correspondence between CAL and LCLE in actual populations

4.1 Database

The data that we use in this paper come from the human mortality database (http://www.mortality.org). The number of country-years for which we can study the correspondence varies depending on the amount of historical data available and the choice of starting age for the calculation of life expectancies and CAL. In this paper we choose three starting ages: 0, 30, and 60. The number of country-years increases dramatically when using a starting age of 60.

4.2 Measurement issues

There are two ways of assessing the correspondence between CAL and LCLE in actual populations. The first option involves the comparison of $e_0^c(t)$ vs. CAL($t+e_0^c(t)$) for each cohort born in year t. In a graph of CAL vs. LCLE, this difference amounts to the vertical difference between the two indicators. The second option involves comparing CAL(t) vs. $e_0^c(t\text{-CAL}(t))$ for each year t. In a graph of CAL vs. LCLE, this difference amounts to the vertical projection of the diagonal difference between the two indicators. These two ways of representing discrepancies between CAL and LCLE can each be analyzed by period or by cohort. Thus there are four different ways of representing the correspondence between CAL and LCLE.

When the correspondence exactly holds, these various ways of representing the correspondence provide the same answer. When there is some discrepancy, however, the amount of discrepancy varies slightly depending on the choice of approach. Nonetheless the results are not substantially different, especially when CAL and cohort life expectancy are calculated on an annual basis.

One complication is that there might be more than one cohort reaching its life expectancy in a given year, as discussed earlier. Therefore there could be more than one vertical difference for a given year. Similarly there could be more than one diagonal difference for a given cohort. A solution to this problem would be to study diagonal differences by year or vertical differences by cohort. However given that one of the goals of this paper is to assess how CAL can be used to assess the life expectancy for the cohort currently reaching its life expectancy, we decided to study vertical differences by year. The existence of multiple vertical differences is rare enough in the mortality database that it can be disregarded in this empirical analysis.

Using age-specific death rates for each year and single-year age groups organized by cohorts, we calculated cohort survival probabilities for each annual cohort centered on January 1. These survival probabilities are then used to calculate cohort life expectancy for each cohort centered on January 1. These cohort survival probabilities are then summed cross-sectionally to calculate CAL for each year centered on January 1. The CAL series is then linearly interpolated to calculate the CAL value corresponding to each value of $t+e_0^c(t)$. The difference between CAL($t+e_0^c(t)$) and $e_0^c(t)$ can then be examined for each year at which CAL($t+e_0^c(t)$) can be calculated.

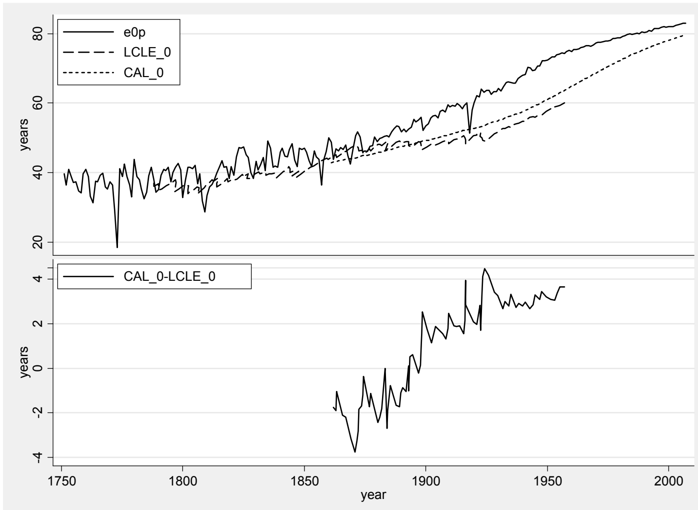
When using a starting age other than 0, the CAL-LCLE correspondence is analyzed in a similar fashion. Defining t as the year at which a given cohort reaches age x, we examine the correspondence between $e_x^c(t)$ and $CAL_x(t+e_x^c(t))$.

4.3 Example: Swedish females

The top panel of Figure 3 shows trends in e_0^p, CAL_0, and $LCLE_0$ among Swedish females. The bottom panel presents the difference between CAL_0 and $LCLE_0$ for the years when the two indicators overlap. During these years, the difference evolves from about -4 years to about +4 years.

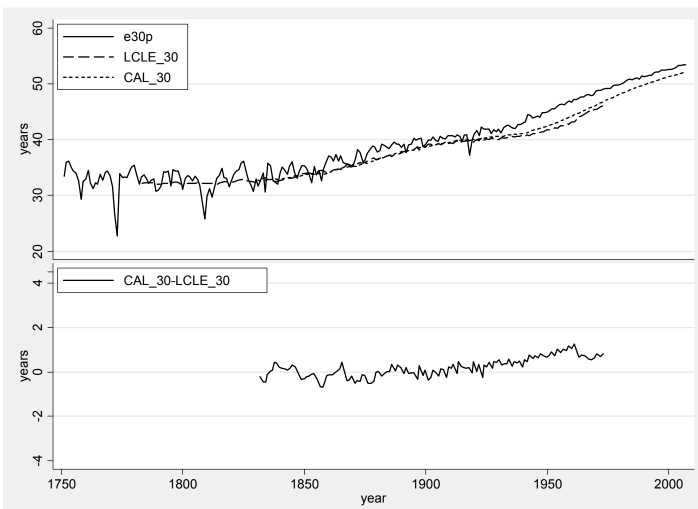
Figure 4 shows the correspondence for life expectancy at age 30. The correspondence dramatically improves in this case. In the later part of the period, however, the difference between CAL and LCLE increases to about 1 year.

Figure 3: Correspondence between CAL_0 and $LCLE_0$ among Swedish females



Source: The Human Mortality Database http://www.mortality.org

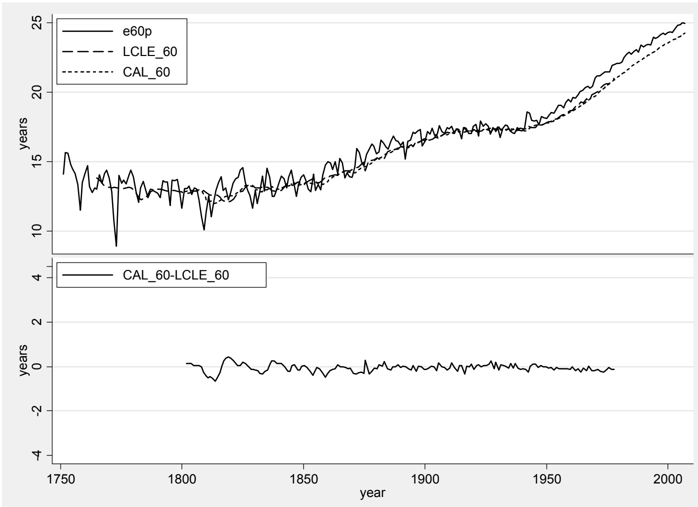
Figure 4: Correspondence between CAL_{30} and $LCLE_{30}$ among Swedish females



Source: The Human Mortality Database http://www.mortality.org

The correspondence for life expectancy at age 60 is shown in Figure 5. At this age the correspondence is excellent. The difference is clearly centered around zero, with only very small deviations. There is no particular trend in the amount of difference.

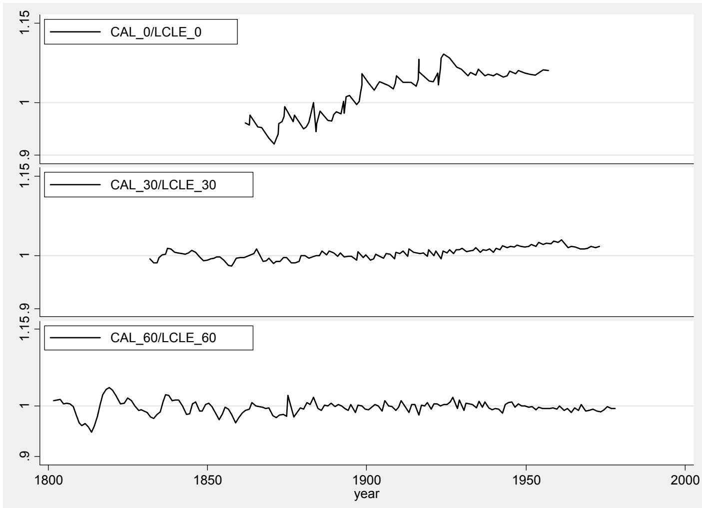
Figure 5: Correspondence between CAL_{60} and $LCLE_{60}$ among Swedish females



Source: The Human Mortality Database http://www.mortality.org

The amount of discrepancy between the two indicators improves between Figure 3 and 5 partly because the level of life expectancy at age 60 is by nature lower than the level of life expectancy at birth. To control for these scale differences, we calculated the ratio (CAL/LCLE) of the two indicators. These ratios are presented in Figure 6. There is a clear improvement in the difference between CAL and LCLE as the starting age increases, even in relative terms. For life expectancy at age 60, the CAL-LCLE correspondence remains excellent.

Figure 6: CAL/LCLE ratio among Swedish Females

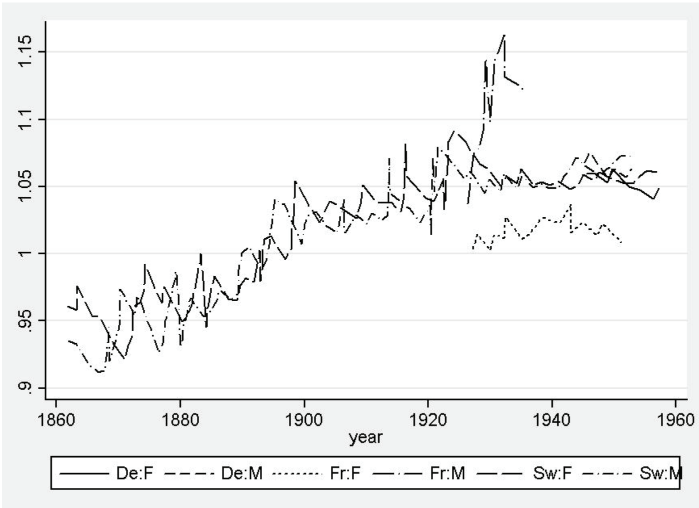


Source: The Human Mortality Database http://www.mortality.org

4.4 Generalization

Figures 7, 8, and 9 generalize the results of Figure 6 to all countries in the mortality database that have sufficient historical information to allow CAL-LCLE comparisons. The patterns found among Swedish females apply here as well. These figures show that the correspondence between CAL and LCLE is not very precise when looking at life expectancy at birth (Figure 7). The ratio of the two indicators varies between about .95 to about 1.05. (French males appear as outliers in this figure, due to the impact of war-related mortality.)

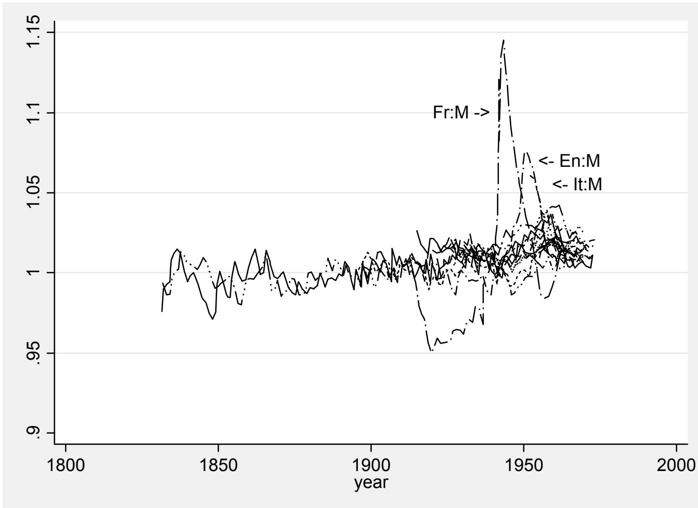
Figure 7: $CAL_0/LCLE_0$ ratio among countries in the human mortality database



Legend: De=Denmark; Fr=France; Sw=Sweden; F=Females; M=Males.
Source: The Human Mortality Database http://www.mortality.org

However the correspondence is very much improved when we use a starting age of 30 (Figure 8), with ratios closer to 1.00 throughout the period (except here also for cohorts experiencing war-related mortality). As in Sweden we do observe a general tendency for an increase in the ratio towards the end of the period, especially after 1950.

Figure 8: $CAL_{30}/LCLE_{30}$ ratio among countries in the human mortality database

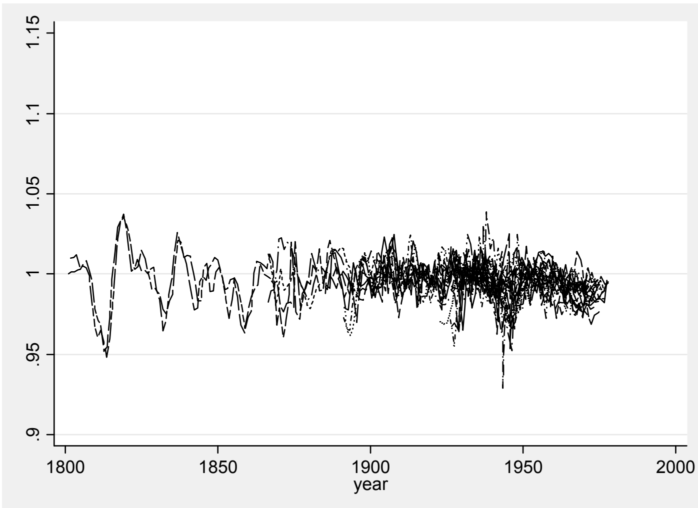


Legend: Fr=France; En=England & Wales; It=Italy; M=Males.
Source: The Human Mortality Database http://www.mortality.org
Note: This figure includes data from the following countries (by sex): Denmark, France, England & Wales, Italy, Netherlands, New Zealand, Norway, Sweden, and Switzerland.

The correspondence is excellent with a starting age of 60 (Figure 9). We see oscillations around 1, with no particular pattern (except for a tendency for CAL_{60} to slightly underestimate $LCLE_{60}$ towards the end of the period). For the country-years presented in the Figure 9, we find that CAL_{60} can be used as a precise proxy for cohort life expectancy at age 60 for the cohort reaching e_{60} in a given year.

These patterns can be interpreted in light of the mortality models described earlier. Life expectancy at birth involves mortality at infant and child ages where mortality does not have a Gompertzian nature and does not shift over time along the age axis. Indeed mortality at infant and child ages decreases with age, while a Gompertz model predicts mortality as an increasing function of age. Given the decreasing nature of age-specific mortality at these ages, a shifting pattern of mortality change is not appropriate either, because it would generate a situation in which age-specific mortality increases overtime at some ages. If instead we examine life expectancy at age 30, which does not take into account the ages at which mortality is a decreasing function of age, the Gompertz model is obviously more adequate. We also find that in many cases mortality at these ages has indeed shifted over time along the age axis in a somewhat linear fashion, especially after 1950. This helps explain why the correspondence is worse at age 0, and then improves as we look at ages 30 and 60.

Figure 9: $CAL_{60}/LCLE_{60}$ ratio among countries in the human mortality database



Source: The Human Mortality Database http://www.mortality.org
Note: This figure includes data from the following countries (by sex): Denmark, France, Finland, England & Wales, Italy, Netherlands, New Zealand, Norway, Spain, Sweden, and Switzerland.

While the correspondence is excellent at ages 60 and above, it is interesting to note that it takes place nonetheless in a context where the two model patterns of mortality change do not exactly apply. Taking Swedish females as an example, age-specific death rates have not been declining at a constant, log-linear rate during the period of interest. In fact there was a stark acceleration in the mortality decline around 1945, producing a sharp increase in period life expectancy at age 60, as shown on Figure 5. Also neither CAL nor LCLE change linearly throughout the period, implying that the linear shift assumption does not hold either. Nonetheless the correspondence remains excellent. This suggests that at these ages deviations from the mortality models have not been substantial enough to produce important discrepancies between the two indicators.

5. Discussion

We find that the correspondence between CAL and LCLE holds exactly or approximately in a number of situations. It holds exactly under the constant shift assumption. It holds approximately under the Gompertz model with log-linear decline. The correspondence also holds extremely well for mortality above age 60 in all populations and time periods available in the human mortality database. Given the regularity of this finding across time periods and contexts, we find that when considering mortality above age 60, CAL provides an accurate estimate of the mean age at death for the cohort currently reaching its life expectancy. LCLE provides a useful way of representing cohort mortality, and we find that CAL can indeed be used as a shortcut for this representation above age 60. Thus the existence of an excellent CAL-LCLE correspondence at these ages provides an additional, concrete interpretation to CAL, an indicator which already has a number of known properties.

However we also find that the CAL-LCLE correspondence is not general. In particular the correspondence is somewhat less accurate at age 30, and far from accurate at age 0. This implies that when it comes to estimating lagged cohort life expectancy at birth or at age 30, CAL should not be used as a proxy. This means that there will be no alternative to mortality forecasts for estimating the current value of LCLE at birth. The mortality forecast approach to LCLE has the added advantage of making it clear what the assumptions are for the cohort's future mortality.

As we said in the introduction the correspondence between CAL and LCLE was first observed in the literature on tempo effects in mortality. Indeed Bongaarts (2005) observed a correspondence, in the linear shift scenario and its Gompertz approximation, between their proposed measures of tempo-adjusted life expectancy (which include CAL, MAD, and M_4) and LCLE. Although they do not propose LCLE as an indicator of tempo-adjusted life expectancy, they interpret this correspondence as a piece of evidence, in the linear shift scenario, that current period life expectancy overestimates life expectancy under current mortality conditions, and that their tempo-adjusted life expectancy corrects for this bias. The logic behind this conclusion is based on a parallel with fertility analysis where lagged cohort indicators are often used. Specifically the TFR for the cohort reaching its mean age at childbearing at time *t* is often compared to the period TFR at time *t* to assess the scale of tempo effects (Ryder 1980; Schoen 2004).

However the use of the lagged cohort TFR in the fertility tempo literature serves a different purpose than the one Bongaarts and Feeney are pursuing in the area of mortality analysis with their tempo-adjusted life expectancy. The TFR for the cohort reaching its mean age at childbearing at time *t* is not meant to capture the level of completed TFR "under fertility conditions of time *t*." It is meant to provide a representation of changes in cohort completed fertility in a way that is more timely than its unlagged counterpart, yet not distorted by changes in the mean age at childbearing like the period TFR (Schoen 2004).

With their tempo-adjusted life expectancy, Bongaarts and Feeney are following a different route. They do not seek to better capture trends in cohort life expectancy. They seek to capture a life expectancy that better reflects underlying period mortality conditions. While CAL and LCLE are equal to one another under the linear shift scenario, they address two drastically different goals in the tempo literature: measuring period conditions vs. tracking cohort behavior.

The contrast between these two approaches is perhaps best illustrated by using Bongaarts and Feeney's "pill" scenario referred to earlier, a scenario in which the linear shift assumption is not met, and where discrepancies between CAL and LCLE arise. In this scenario, starting from a situation in which mortality is constant, all individuals present in the population at a given time see their age at death extended by a fixed amount. In other words, in this scenario new mortality conditions appearing during a given year produce fixed delays in future cohort deaths. An example of this life extension pill scenario is represented in Figure 10. This figure illustrates that under this specific mortality scenario, CAL immediately adjusts to the ultimate level of cohort life expectancy and may thus better reflect the underlying mortality conditions than period life expectancy during that year (Bongaarts and Feeney 2003; Guillot 2006). Figure 10 also shows that while CAL adjusts immediately under this scenario, cohort life expectancy (and thus LCLE) adjusts only gradually to this ultimate level. (This is also shown by Rodriguez (2006) and Goldstein (2006).) In particular the level of LCLE anticipates the change in mortality conditions and starts increasing before these new mortality conditions appear. In this scenario as expected, the CAL-LCLE correspondence does not hold, and it is CAL, rather than LCLE, that correctly indicates the underlying mortality conditions. LCLE shows the implication for cohorts of this change in mortality conditions, and illustrates how variations in period life expectancy may provide an exaggerated indication of variations in cohort life expectancy. However this example also illustrates that LCLE is not an adequate indicator of these underlying conditions. CAL and LCLE may be equal to one another in a number of situations, as we show in this paper, but they refer to two different goals in the tempo literature.

Figure 10: e_0^p, CAL_0 and $LCLE_0$ in Bongaarts and Feeney's single shift scenario.

LCLE is useful in other respects. In particular associating cohort life expectancy with its corresponding mean year at death is a useful way of summarizing many years of mortality influences, spanning the entire life course of a cohort. However average year at death for a given cohort appears to have little to do with the underlying mortality conditions of that year.

6. Acknowledgements

An earlier version of this paper was presented at the XVI IUSSP International Population Conference, 2 October 2009, in Marrakech, Morocco, and at the 2010 PAA meetings, in Dallas, TX. The authors would like to thank John Bongaarts, Sam Preston, Ken Land, and anonymous referees for helpful comments and suggestions. This research was supported in part by funding from the Center for Demography of Health and Aging, University of Wisconsin-Madison [NIA P30 AG017266].

References

Bongaarts, J. (2005). Five measures of period longevity. *Demographic Research* 13(21): 547-558. doi:10.4054/DemRes.2005.13.21.

Bongaarts, J. and Feeney, G. (2003). Estimating mean lifetime. *Proceedings of the National Academy of Sciences* 100(23): 13127–13133. doi:10.1073/pnas.2035060100.

Bongaarts, J. and Feeney, G. (2006). The quantum and tempo of life-cycle events. *Vienna Yearbook of Population Research* 2006: 115–151. doi:10.1553/populationyearbook2006s115.

Brouard, N. (1986). Structure et dynamique des populations. La pyramide des années à vivre, aspects nationaux et exemples régionaux. *Espaces, Populations, Sociétés* (2): 157–168.

Goldstein, J. (2006). Found in translation: A cohort perspective on tempo-adjusted life expectancy. *Demographic Research* 14(5): 71–84. doi:10.4054/DemRes.2006.14.5.

Goldstein, J. and Wachter, K. (2006). Relationships between period and cohort life expectancy: Gaps and lags. *Population Studies* 60(3): 257-269. doi:10.1080/00324720600895876.

Guillot, M. (1999). *The period average life (PAL)*. Paper presented at the PAA annual meeting, New York City, USA, March 25-27, 1999.

Guillot, M. (2003). The cross-sectional average length of life (*CAL*): A cross-sectional mortality measure that reflects the experience of cohorts. *Population Studies* 57(1): 41–54. doi:10.1080/0032472032000061712.

Guillot, M. (2005). The momentum of mortality decline. *Population Studies* 59(3): 283–294. doi:10.1080/00324720500223427.

Guillot, M. (2006). Tempo effects in mortality: An appraisal. *Demographic Research* 14(1): 1-26. doi:10.4054/DemRes.2006.14.1.

Keilman, N. (2006). Demographic translation: From period to cohort perspective and back. In: Wunsch, G., Caselli, G., and Vallin, J. (eds.). Demography: Analysis and Synthesis. Burlington, San Diego, and London: Elsevier: 215-225.

Rodriguez, G. (2006). Demographic translation and tempo effects: An accelerated failure time perspective. *Demographic Research* 14(6): 85-110. doi:10.4054/DemRes.2006.14.6.

Ryder, N. (1980). Components of temporal variations in American fertility. In: Hiorns, R.W. (ed.). *Demographic Patterns in Developed Societies*. London: Taylor & Francis: 15-54.

Schoen, R. (2004). Timing effects and the interpretation of period fertility. *Demography* 41(4): 801-819. doi:10.1353/dem.2004.0036.

Wachter, K. (2005). Tempo and its tribulation. *Demographic Research* 13(9): 201–222. doi:10.4054/DemRes.2005.13.9.

Wilmoth, J. (2005). On the relationship between period and cohort mortality. *Demographic Research* 13(11): 231-280. doi:10.4054/DemRes.2005.13.11.