

MARC LUY* – CHRISTIAN WEGNER*

Conventional versus tempo-adjusted life expectancy – which is the more appropriate measure for period mortality?

1. INTRODUCTION

Life expectancy is still the most common measure for period mortality. Compared to other mortality measures life expectancy has the advantage of a distinct meaning with an easily understandable interpretation. For instance, a difference in life expectancy of 1.5 years between two populations in a certain year is much easier to assess than a difference in standardized death rates of, let's say, 0.0016. The same holds for showing the extent of mortality differences or the effects of changes in specific age groups or causes of death on overall mortality of a population. These specific characteristics make life expectancy the most important mortality measure for practical purposes, such as policy-making.

Recently, discussion of period life expectancy has taken a new turn among demographers. In a series of papers, Bongaarts and Feeney (2002, 2003, 2006) suggested the use of tempo-adjusted life expectancy for the analysis of period mortality because conventional life expectancy is affected by tempo distortions. Unlike the discussion of mortality tempo adjustment in recent years (see the collection of papers in Barbi *et al.*, 2008) we want to focus on the question what characteristics a measure for period mortality should have and how these characteristics are met in conventional and tempo-adjusted life expectancy. In this context the most important question is how conventional and tempo-adjusted life expectancy reflect the period mortality of two populations experiencing different changes in (age-specific) mortality. We analyze these questions with a simple model population consisting of only four age groups. Nevertheless, the results are important for every kind of empirical mortality analysis comparing different populations, above all because the relations are represented in this paper in discrete time as they occur in practical mortality analysis. The reason for choosing such a simple population model is that it allows us to follow the future occurrence of postponed deaths more easily. As will be shown, this is

* Vienna Institute of Demography, Austrian Academy of Sciences. Corresponding author: Marc Luy; e-mail address: mail@marcluy.eu

the key for understanding the different assumptions behind conventional and tempo-adjusted life expectancy which lead to different consequences regarding the reflected period mortality conditions.

In the present paper we explain two main conclusions of our reflections: (i) we show a technical aspect behind period life table construction that has not been discussed so far and that shows why – according to our understanding of the *technical purpose* of a period measure – tempo-adjusted life expectancy is a more appropriate tool for standardizing period mortality than conventional life expectancy, and (ii) we show why – according to our understanding of the *practical purpose* of a period measure – conventional life expectancy can be misleading whereas tempo-adjusted life expectancy cannot. We are aware that other scholars might see the meaning of the technical and practical purposes of a period mortality measure in a different perspective. However, our considerations allow us to derive an interpretable definition for tempo-adjusted life expectancy. Such a definition is still missing in the demographic literature, which may be one of the main reasons for the general rejection of mortality tempo-adjustment. Finally, we present estimates for tempo-adjusted life expectancy for the period 2001-2005 for 41 countries. This empirical application demonstrates that tempo effects and their adjustment are not only a theoretical problem but can have significant impacts on the interpretation of levels and trends of period mortality.

2. PRACTICAL AND TECHNICAL PURPOSES OF A PERIOD MEASURE: DEMANDS ON PERIOD LIFE EXPECTANCY

Our perspective is determined by the requirement that – in order to fulfil the above-mentioned purposes – a period mortality measure should include only the current mortality conditions, *i.e.* the mortality conditions of the calendar year(s) analyzed. A period measure for mortality should enable us to compare exclusively the period-specific mortality conditions of two or more populations or the changes between two or more periods. From the demand “exclusively period-specific conditions” it follows that the calculated value itself is not expected to have a specific meaning for any cohort since period life expectancy contains the mortality of 100 different cohorts, each contributing approximately one percent to the overall mortality of a specific period. We know that no cohort will ever experience the age-specific mortality schedule of 100 different cohorts at 100 different ages at a certain moment of time. This is why period life expectancy refers to a “hypothetical” cohort of people. Nevertheless, according to our perspective, the mortality of the 100 real cohorts should be reflected in period life

expectancy in the sense that an increase/decrease of period life expectancy must coincide with an increase/decrease of the life expectancy of (at least the majority of) the cohorts living during the period analyzed. The reason behind this demand is that the *practical purpose* of a period measure is to get information about the current mortality conditions of a population. This information should enable us to evaluate if the mortality of a population (meaning the real members of the population) decreases or increases (or is higher or lower than in other populations) so as to provide a basis for necessary or possible measures to improve survival conditions (for the real members of the population). Thus, period measures are calculated to get information about the real population – and this is why the real mortality of the currently living cohorts must be reflected in the hypothetical life expectancy based on period mortality conditions measured through age-specific death rates prevailing in a specific period.

The *technical purpose* of a period measure is to standardize the current demographic conditions for all compositional effects disturbing its practical purpose. In the following pages we show that both conventional and tempo-adjusted life expectancy standardize for such effects, but in a different manner. Since, as we have indicated, period measures are hypothetical by their very nature, it is not possible to conclude that one form of standardization is correct and the other incorrect. But it is possible to think about what consequences the two forms of standardization have for the parameter calculated and if these consequences meet the practical purpose of the measure. In order to do so, a period measure of mortality should include neither past mortality nor assumptions regarding (possible) future mortality since both refer to conditions outside the observation period. Measures, including the past mortality of the current living cohorts, should be separated from period measures, and might – in accordance with the analysis of fertility – be called “timing measures”. In this understanding, the “cross-sectional average length of life” (CAL) as introduced by Brouard (1982) and Guillot (2003) would belong to the group of timing measures, as does the “average completed fertility” (Ward and Butz, 1980). On the other hand, measures regarding the future mortality of the current living cohorts should be treated and seen as cohort projections. Both, timing and cohort measures should be strictly separated from period measures and not mixed with each other. This does not mean that period conditions cannot be affected by past trends. Former mortality conditions might indeed affect current conditions, e.g., through selection effects. Thus, past trends and conditions must be used for interpreting specific period conditions in the sense that they might explain higher or lower current mortality levels.

In the subsequent sections we show that conventional life expectancy does not meet our demands on a period mortality measure since it includes specific assumptions regarding future mortality that differ between different populations. These characteristics of conventional life expectancy can lead to paradoxes like decreasing period life expectancy, while all successive cohorts experience successive increasing life expectancy, or a situation in which period life expectancy indicates a higher level for one population as compared to another, while each cohort of the population with higher period life expectancy has a lower life expectancy than the corresponding cohort of the other population. Tempo-adjusted life expectancy, however, is free of these distorting effects and thus enables the analysis and comparison of pure period-specific mortality conditions.

3. A SIMPLE MORTALITY MODEL FOR COMPARING CONVENTIONAL AND TEMPO-ADJUSTED LIFE EXPECTANCY

In order to demonstrate why we think that conventional life expectancy does not meet the practical and technical purposes of a demographic period measure we use a very simple population model consisting of four single age groups. The same simulations and calculations could be done with a more complex population containing 100 or 110 single ages. We prefer the simple model because it enables us to more easily follow the consequences of mortality changes for each age group and the total population. The starting point is a closed population with a constant number of annual births of 1,000 and constant age-specific mortality conditions (probabilities of dying). According to these mortality conditions, 200 individuals die at age 0, 100 at age 1, 500 at age 2, and the remaining 200 survivors die at age 3. “Constant conditions” means that these numbers occur identically for each cohort and in each single calendar year. Note that our calculations of the probabilities of dying q_x are based on the so-called “birth-year method” as proposed in the 19th century by Becker (1869, 1874) and Zeuner (1869, 1894, 1903). This is the intuitively correct way of calculating probabilities of dying which might be assumed to be free of tempo effects, unlike the typical estimation from age-specific death rates. Our models show, however, that the birth-year method contains tempo effects like any other method of q_x calculation. The age-specific number of survivors, deaths and probabilities of dying for our model are given in Table 1.

Difficulties in calculating and interpreting period life expectancy arise only in situations of changing mortality conditions. In the development of human mortality, changes have mainly been characterized by improvements of mortality which lead younger cohorts to live longer and thus the members

Table 1 – *Number of survivors at age x, deaths and resulting probabilities of dying of the model population*

Age x	Survivors	Deaths	q_x
0	1,000	200	0.200
1	800	100	0.125
2	700	500	0.714
3	200	200	1.000

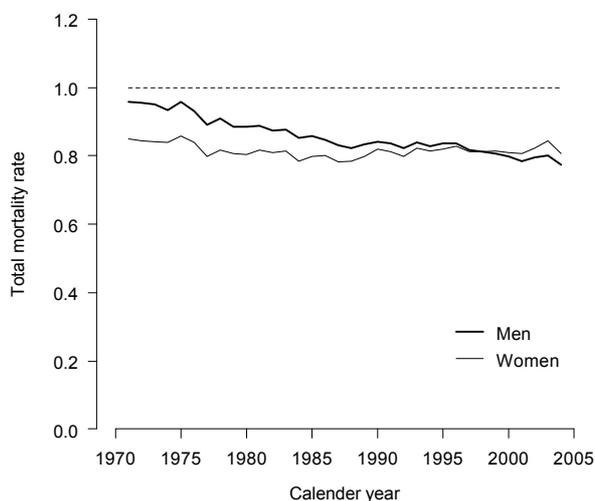
of younger cohorts to die later on average than their counterparts from older cohorts. A logical consequence of such changes is that the deaths of younger cohorts are postponed to a later moment in time (as compared to the survival of older cohorts). Compared to constant mortality conditions, this leads to a postponement of deaths (from a specific period) to a later moment. The consequences of this effect on period mortality – what Bongaarts and Feeney call the “tempo effect” – can be shown by the total mortality rate (TMR) as introduced by Sardon (1993, 1994). As described by Guillot (2006: 4), “in a cohort (real or synthetic), the TMR is the number of lifetime deaths divided by the initial size of the cohort. In a life table with a radix of one, the TMR can be calculated by adding all age-specific life table deaths. Obviously, the TMR in a cohort, real or synthetic, is invariably one”. The TMR can also be calculated cross-sectionally for a specific period. In this case, for each cohort alive in the observation period, the proportion of deaths occurring during that period (adjusted for all migrations until the observation period) is calculated and then these proportions are summed across all cohorts (for more details, see Guillot 2006). In principle, the TMR can be seen as the mortality equivalent to the fertility measure “timing index” (Butz and Ward, 1980), reflecting the degree of completeness of the cross-sectional sum of cohort events. Like the timing index in the case of fertility, the TMR equals 1.0 when mortality remains unchanged. As soon as some or all currently living cohorts experience a change in mortality conditions, the TMR leaves unity and becomes higher than 1.0 in the case of increasing mortality and lower than 1.0 in the case of decreasing mortality.

Figure 1 shows the TMR for West German women and men from 1970 to 2005. The TMR lies below 1.0 in all calendar years. This is the logical consequence of the improving survival conditions observable in almost every developed country for many decades¹. These empirical values for the TMR show that some deaths are “missing” in the period perspective. However, in the period life table the quantum of mortality (and thus the TMR) is 1.0 since

¹ Exceptions are the eastern European countries from the former Soviet Union where life expectancy mainly decreased during the last decades.

all members of the life table population die until the highest age. Consequently, the missing deaths from the empirical data must have been redistributed inside the life table before deriving the parameter life expectancy – this holds for both conventional and tempo-adjusted calculations. This is the starting point of an alternative view on the differences between conventional and tempo-adjusted life expectancy. Interestingly, this view reveals that both conventional and tempo-adjusted calculations standardize for the tempo effect-caused absence of period deaths. The difference between conventional and tempo-adjusted life expectancy can be seen as a consequence of the way the missing deaths are redistributed inside the life table, or, in other words, how tempo effects are standardized. What these differences look like and what consequences they have regarding the practical and technical purposes of a period measure can be followed in our model population. The modelling is driven by the idea of reconstructing the hypothetical cohort of the life table population as a result of the assumptions behind conventional and tempo-adjusted standardization. Note that the use of the birth-year method leads the age-specific estimates to always span two calendar years. For simplicity, in the following text only the first of these two years is given, *i.e.* “year 1” refers to birth-year type calculated probabilities of dying of years 1 and 2, “year 2” refers to birth-year type probabilities of dying of years 2 and 3, and so forth.

Figure 1 – *Total Mortality Rate (TMR) for West German women and men, 1970-2005*



Source: own calculations with data from Statistisches Bundesamt (2006).

We assume that the constant, *i.e.* stationary, conditions as given in Table 1 remain unchanged until year 1. In year 2 we model an improvement of survival conditions in the population, leading to a reduction of deaths by 10 percent in each age group. Thus, in year 2 the corresponding numbers of deaths are 180 at age 0, 90 at age 1, 450 at age 2, and 180 at age 3. Compared to the situation before, 100 deaths (10 percent of 1,000) have been saved: 20 at age 0, 10 at age 1, 50 at age 2 and 20 at age 3². This shift of deaths leads to an “incomplete” pattern of death numbers in year 2. Calculating the TMR for that year yields 0.9 ($180/1,000 + 90/1,000 + 450/1,000 + 180/1,000$), reflecting the relative amount of postponed deaths due to the survival improvement. As was shown in figure 1, a TMR of 0.9 is a realistic representation of current mortality trends in developed countries.

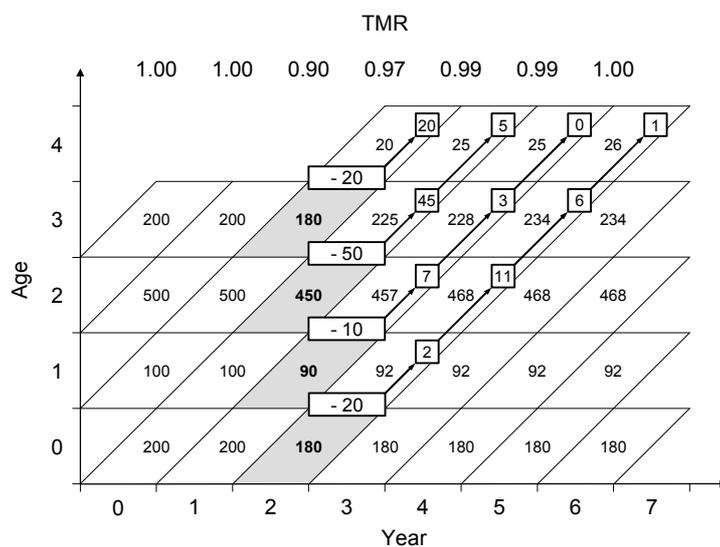
Assume we are living in year 3 and we want to calculate life expectancy for year 2. From the modelled 10 percent reduction of the number of deaths in each age follows that the probabilities of dying q_x reduce by 10 percent as well. These q_x can be used to construct a period life table. Since we know that in this life table the TMR will equal 1.0 we can conclude that the 100 missing deaths in year 2 must have been redistributed within the corresponding period life table. In the following, we reconstruct this redistribution according to the conventional and the tempo-adjusted methodology, respectively. The goal is to visualize the consequences of the corresponding assumptions for the life table cohort born in year 2, *i.e.* the “hypothetical” cohort to which the estimated life expectancy refers, as well as for all other cohorts living in year 2 and how their life expectancy compares to the estimated period life expectancy.

Figure 2 shows the redistribution of postponed deaths according to the conventional life table method. Each parallelogram represents the age-specific number of deaths underlying the derived probabilities of dying according to the birth-year method. The deaths occurring in the period of changing mortality are highlighted by grey-shaded parallelograms. The numbers in the rectangles on the top of these parallelograms reflect the deaths postponed as compared to the preceding stationary conditions, *i.e.* 20 deaths at age 0, 10 deaths at age 1, 50 deaths at age 2 and 20 deaths at age 3. The basic assumption of the conventional life table is that the current probabilities of dying q_x derived from the deaths in the grey-shaded parallelograms remain constant in all future years. As a consequence, the hypothetical cohort of newborns will experience exactly these probabilities of dying during their complete life course. Moreover, from the assumption of constant q_x it follows that the 100 postponed deaths are redistributed into

² Here we assume a shift to the now reachable age of 4. Note that assuming a constant highest age of 3 would not affect the basic conclusions.

higher ages and thus into the following years according to the current (and from now on constant) q_x schedule. The small squares in Figure 2 illustrate this redistribution of postponed deaths into the subsequent ages. For example, 2 of the 20 postponed deaths at age 0 occurred at age 1, 11 at age 2, 6 at age 3 and 1 at age 4. It can be seen in Figure 2 that according to the conventional life table assumption this process takes the whole lifetime of the hypothetical cohorts. In other words, the standardization procedure of the conventional life table technique leads to a specific assumption regarding the future survival of the deaths saved. The exact pattern of their redistribution depends on the current age-specific mortality schedule. This mortality schedule includes both the age-specific probabilities of dying and the number of postponed deaths in the period analyzed. The latter follows from the fact that the probabilities of dying q_x are based on mortality conditions leading the TMR to being below 1.0. Furthermore, the TMR reflects the number of deaths that have to be redistributed (and thus the relative impact of this redistribution). Consequently, for populations with different TMR, different q_x and different tempo effects the conventional life table technique assumes different trends regarding the future mortality of the hypothetical cohorts constructed, as will be shown in the subsequent section. However, we can already conclude that changing mortality should be seen as a compositional effect that a period measure should adjust for.

Figure 2 – *Redistribution of postponed deaths according to the conventional life table assumption*



As long as we assume that each person has to die, the effect of missing deaths is a temporary event since they must occur at some time in the future. The assumption of the conventional life table is one out of an infinite number of possibilities of what might happen to these postponed deaths. One might argue that this assumption is plausible given the current mortality changes. However, it is interesting that this assumption does not result in constant mortality conditions for the future years through which the hypothetical cohort born in year 2 runs during its life course. This can be seen by the values for the corresponding TMR as given at the top of Figure 2. Thus, according to the conventional life table assumption the TMR becomes 0.97 in year 3, 0.99 in years 4 and 5 and becomes 1.0 in year 6 when the last cohort affected by the mortality changes became extinct (TMRs calculated as described before). Since the desired interpretation of life expectancy is that it reflects the average age at death of a newborn under the assumption that the current mortality conditions remain constant, we can see that this desire is not fulfilled in conventional life expectancy for a period with changing mortality conditions. What remains constant are the age-specific probabilities of dying which are affected by tempo effects. The TMR shows that under the conventional life table assumptions the future period mortality conditions of the hypothetical population are not constant until all deaths postponed in the observation period are redistributed, *i.e.* until the youngest cohort alive in the observation period becomes extinct. The age distribution of survivors under the new constant conditions according to the conventional life table assumption, which apply from year 6 on, and the corresponding probabilities of dying, which are constant since year 2, can be found in Table 2.

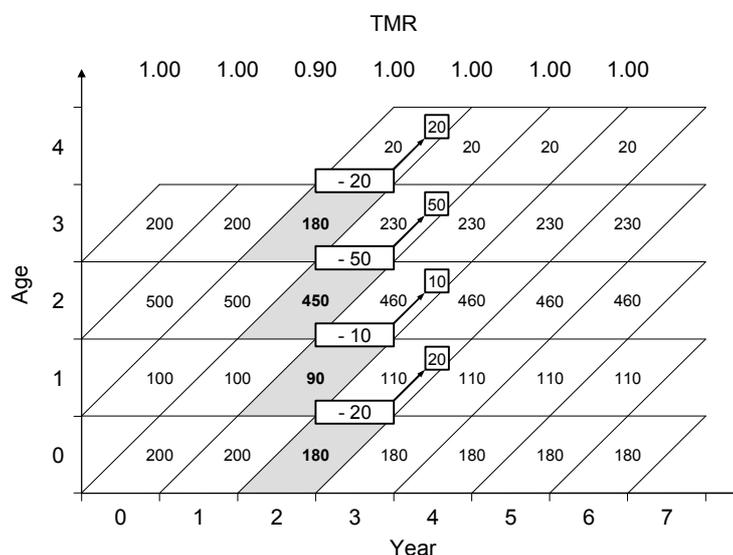
Up to this point, however, it is not clear if these consequences of the conventional life table assumption are a problem regarding the practical and technical purposes of a period measure. Before answering this question we

Table 2 – Number of survivors at age x and probabilities of dying of the model population in the new constant mortality conditions according to the conventional life table assumption and the Bongaarts/Feeney assumption

Age x	Conv. life table assumption		Bongaarts/Feeney assumption	
	Survivors	q_x	Survivors	q_x
0	1,000	0.1800	1,000	0.1800
1	820	0.1125	820	0.1341
2	728	0.6429	710	0.6479
3	260	0.9000	250	0.9200
4	26	1.0000	20	1.0000

have to look at the assumptions behind tempo-adjusted life expectancy in a similar manner. Tempo-adjusted life expectancy is based on a different scenario regarding the future outcome of the postponed deaths. The basic assumption here is that all postponed deaths occur in the next calendar year, as demonstrated in Figure 3³. This assumption could be seen as the most conservative, however, with the consequence that the assumed future trends immediately result in constant period conditions for the hypothetical population. As can be seen in Figure 3, the age-specific number of deaths remains constant from year 3 on, as does the age-specific distribution of survivors. The latter can be found in Table 2. Table 2 also shows the corresponding probabilities of dying, which remain constant from year 3 on as well. That the Bongaarts and Feeney assumption immediately leads to new constant conditions can also be seen when the TMR is considered. According to the assumptions of tempo-adjusted life expectancy the TMR becomes 1.0 in year 3, the year following the changes in mortality, and remains constant for all future years (more details on the consequences of the Bongaarts/Feeney assumption are presented in the subsequent section).

Figure 3 – *Redistribution of postponed deaths according to the Bongaarts/Feeney assumption*



³ A similar illustration of the Bongaarts and Feeney assumption can be found in Guillot (2006).

In other words, tempo-adjusted life expectancy provides a way of standardizing current mortality changes that is identical for any population analyzed regardless the characteristics of tempo effects in the observation year. Any change in mortality conditions is standardized in such a way that the TMR is 1.0 for all future years.

4. A DEFINITION OF TEMPO-ADJUSTED LIFE EXPECTANCY

When demographers analyze current period mortality conditions they do not know how mortality will develop and thus how the survival of postponed deaths will unfold. Let's assume first that the future will be as stated by the conservative assumption behind tempo-adjusted life expectancy (Bongaarts/Feeney assumption). Figure 4 shows that for this situation, conventional period life expectancy increases from the constant level of 2.20 years to 2.33 years in the time of mortality change (year 2) and declines directly after to the new constant level of 2.30 years. Figure 4 also shows the development of cohort life expectancy of all cohorts living during the years of changing mortality. Note that the cohort life expectancies are represented as lagged cohort life expectancies, *i.e.* the life expectancy of the cohorts is displayed at the average year of death of the members of the cohorts (birth year + life expectancy)⁴. Two important aspects become visible: (i) no cohort ever reaches the level of conventional period life expectancy of year 2, and (ii) all successive cohorts experience successively higher life expectancies. There is no decline in life expectancy among cohorts as indicated by conventional life expectancies between years 2 and 3. If in an empirical application period life expectancy indicated such a decline of life expectancy this would probably be interpreted as an increase (or worsening) of mortality. Figure 4 shows, however, that in this example no cohort experiences an increase of mortality compared to the previous cohorts. On the other hand, tempo-adjusted period life expectancy of year 2 lies between the old and new constant levels of life expectancy. This makes sense since year 2 is the period of transformation between these two mortality levels.

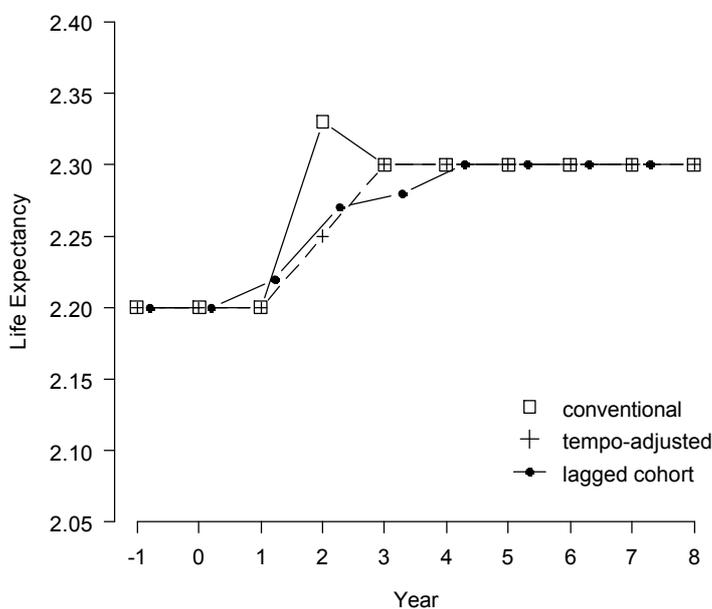
The example presented in Figure 4 provides a possibility to give tempo-adjusted period life expectancy an interpretable meaning. Thus, *tempo-adjusted life expectancy can be interpreted as the average of life expectancies of all hypothetical cohorts living during the observed period, assuming that all currently saved deaths occur instantly in the next period.* The cohorts alive during year 2 are the cohorts born in year 2 (life

⁴ More detailed descriptions of the lagged cohort life expectancy and empirical estimates can be found in Bongaarts (2005), Goldstein (2006) and Rodríguez (2006).

expectancy 2.30 years), year 1 (2.28 years), year 0 (2.27 years), and year -1 (2.22 years). Since we assumed that deaths postponed from the former highest reachable age 3 now occur in age 4 we also have to take into account the cohort born in year -2 (life expectancy 2.20 years) since this cohort would have reached age 4 in year 2. Thus, the average of cohort life expectancies is $(2.30+2.28+2.27+2.22+2.20) / 5 = 2.25$ years. As can be seen in Figure 4, this is the same value as provided by tempo-adjusted period life expectancy. Since the old mortality conditions resulted in a life expectancy of 2.20 years and the new mortality conditions resulted in a life expectancy of 2.30 years, a value of 2.25 years seems the appropriate description of period mortality conditions in the year of changing mortality.

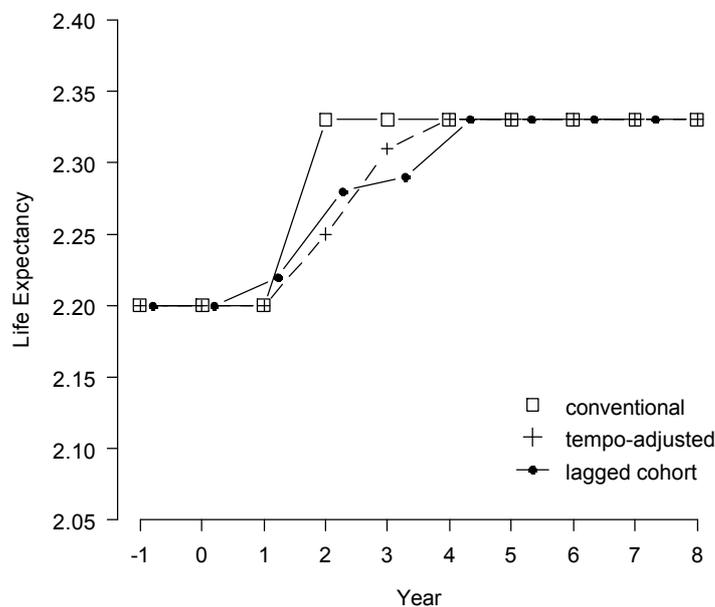
It is easy to see that a similar definition is not possible for conventional period life expectancy even under the assumption that future mortality develops according to the assumptions of the conventional life table method. This can be seen in Figure 5 where the same calculations are made for the case that mortality changes as assumed by the conventional way of determining life expectancy (conventional life table assumption). The graph shows that also in this case the trend of tempo-adjusted life expectancy is

Figure 4 – Trends in period, tempo-adjusted and lagged cohort life expectancy assuming that postponed deaths occur in the next period (Bongaarts/Feeney assumption)



similar to the trend of cohort life expectancies. Furthermore, the interpretation of tempo-adjusted life expectancy as an average of hypothetical life expectancies of all cohorts living during the observed period, assuming that all currently postponed deaths occur in the subsequent period, holds true here as well. The trend of moderately increasing tempo-adjusted life expectancy as compared to the conventional period life expectancy also seems logical from the point of view that in year 2 only one cohort fully experiences the new mortality conditions whereas the majority of living cohorts experienced the old mortality conditions during most of their life courses. Conventional life expectancy, on the other hand, can only be interpreted as the average life expectancy of current newborns, assuming that the current age-specific q_x schedule remains constant. The examples presented in Figures 4 and 5 show that this assumption is not an appropriate way to standardize mortality conditions in a period of changing mortality. Note that in practical application the cohorts as shown in Figure 4 would be hypothetical cohorts constructed on the basis of current mortality conditions assuming that they belong to a stationary population until the year of mortality change (*i.e.* in practical application the year of observation) and assuming a specific future destiny of currently postponed deaths without any

Figure 5 – Trends in period, tempo-adjusted and lagged cohort life expectancy assuming constant q_x (conventional life table assumption)



further or additional changes of mortality in the subsequent years. Thus, the aim of tempo-adjusted life expectancy must not be seen to produce an estimate for real cohort life expectancy. The hypothetical cohorts constructed for tempo-adjusted life expectancy are only an instrument for standardizing period mortality conditions to a new constant level. As was shown in the previous section, this does not hold for the hypothetical cohorts according to the conventional life table assumption. Instead, conventional life expectancy represents a cohort projection for the currently newborn including specific assumptions of changing future mortality, as can be seen clearly in Figure 5.

5. CONVENTIONAL AND TEMPO-ADJUSTED LIFE EXPECTANCY FOR POPULATIONS WITH DIFFERENT CHANGES OF MORTALITY CONDITIONS

The undesired consequences of the assumptions behind conventional life expectancy become most apparent when we consider two populations that experience different changes in their mortality conditions. This is the typical situation demographers are always faced with when they compare different populations by means of period life expectancy. To demonstrate this situation we add a second population to our model. This population is called “population B” while the population used in the previous sections remains unchanged and is now called “population A”. As with population A, in population B the number of births remains constant at 1,000 and mortality remains unchanged until year 1. In the first case, in year 2 both populations experience a reduction in mortality conditions with all postponed deaths occurring in the next year 3 (Bongaarts/Feeney assumption). Thus, from year 3 on, mortality remains constant in both populations, as modelled for population A in the first example of the previous section.

In our model, the assumed changes in mortality conditions occur in the same way in both populations. However, the two populations differ in the level of mortality and the pace of mortality reduction. Population B has higher mortality at any given time. Until year 1 the probabilities of dying in population B are 10 percent higher than in population A leading to a life expectancy of 2.09 years for population B, compared to 2.20 years for population A. During year 2, the probabilities of dying decrease by 10 percent in population A and by 20 percent in population B. Although the reduction in population B is twice the reduction in population A, the improvements are insufficient to reach the mortality level of population A. In the new constant conditions from year 3 on, population A’s life expectancy is 2.30 years and the life expectancy of population B is 2.29 years. From these assumptions it follows that every single cohort of

population A has a higher life expectancy than the corresponding cohort of population B (see Figure 6).

However, as a consequence of the more intensive changes in population B during year 2, conventional life expectancy is higher for population B in that year. The conventional period life expectancy for population B is 2.37, whereas the conventional life expectancy of population A is 2.33 (see solid lines in Figure 7). Usually, every analysis based on such period results would conclude that current mortality conditions are lower in population B than in population A. In fact, from Figure 6 we know that no cohort in population B lives longer than the corresponding cohort of population A. Tempo-adjusted life expectancy, however, provides the desired results, indicating higher mortality conditions for population B, as can be seen from the broken lines in Figure 7. Furthermore, as was shown in the previous sections, this is yet another example where the conventional way of calculating period life expectancy yields values that no cohort of both populations ever reaches. On the other hand, tempo-adjusted life expectancy averages the life expectancies of the cohorts living during the period of changing mortality.

Figure 6 – *Lagged cohort life expectancies for the cohorts of populations A and B assuming that postponed deaths occur in the next period (Bongaarts/Feeney assumption)*

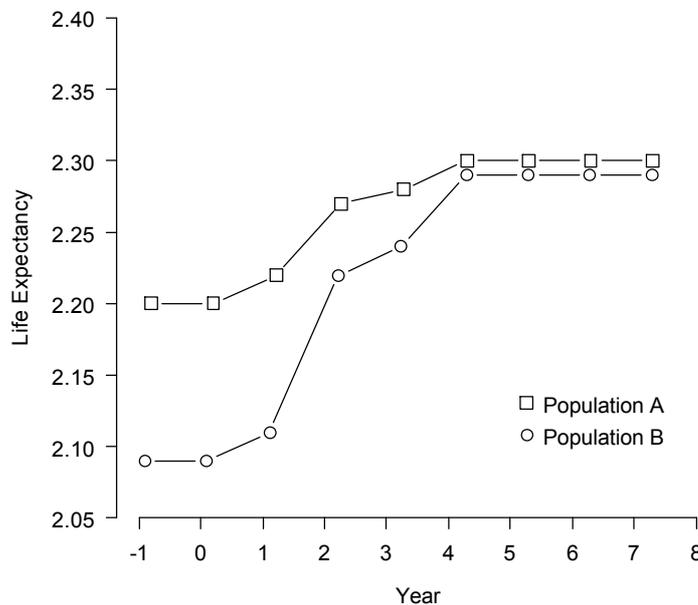
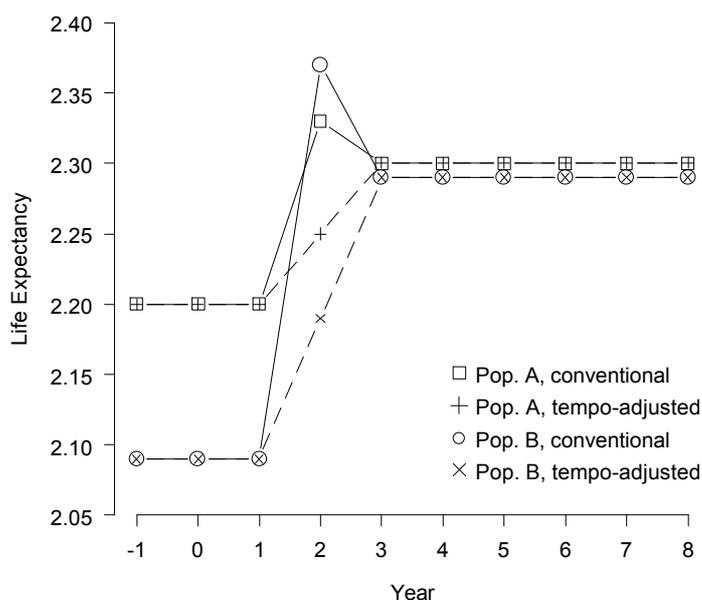
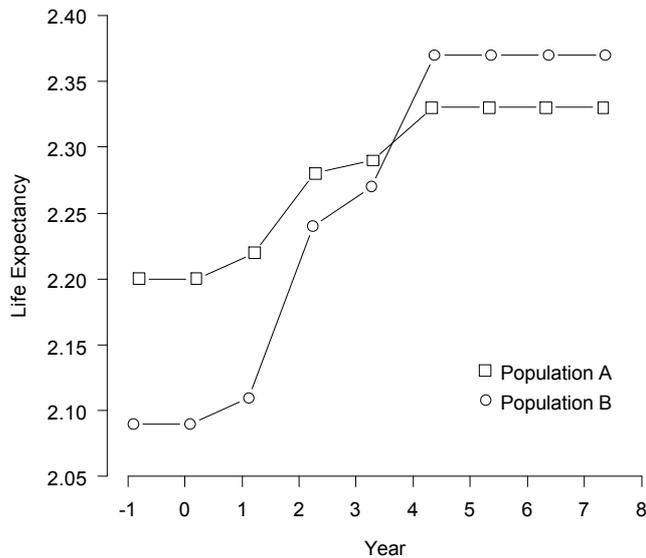


Figure 7 – *Conventional and tempo-adjusted period life expectancy for population A and population B assuming that postponed deaths occur in the next period (Bongaarts/Feeney assumption)*



Let us now consider conventional and tempo-adjusted life expectancy for populations A and B for the case in which mortality changes according to the conventional life table assumption. Figure 8 shows the corresponding changes in cohort life expectancy in the two populations. Since, according to the conventional life table assumption, the q_x schedule predominant in year 2 remains constant for all subsequent years, the younger cohorts of population B experience a higher life expectancy than the corresponding cohorts of population A (see crossing-over of lagged cohort life expectancies in Figure 8). In this example, the crossing-over is visible in both period indicators, conventional and tempo-adjusted life expectancy (see Figure 9). However, tempo-adjusted life expectancy better reflects the trends of the real population, where in most cohorts alive in year 2 those in population A still experience a higher life expectancy than their counterparts in population B. From this point of view, the later crossing-over of tempo-adjusted life expectancy provides a more appropriate picture of the mortality conditions of the currently living cohorts than does the immediate crossing-over of conventional life expectancy.

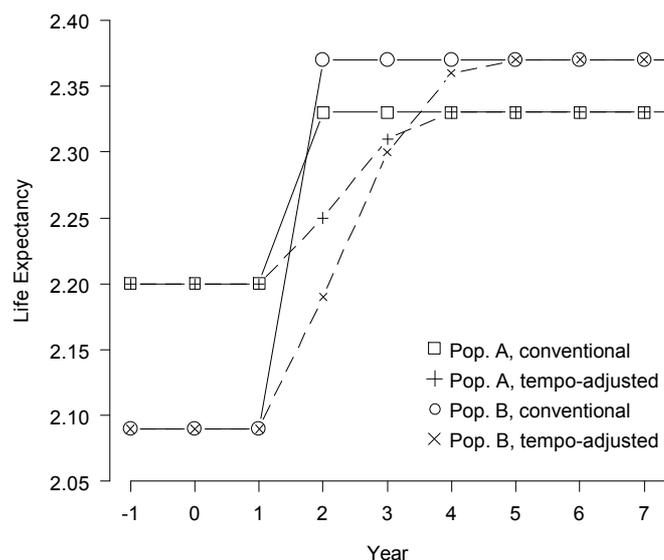
Figure 8 – *Lagged cohort life expectancies for the cohorts of populations A and B assuming constant q_x (conventional life table assumption)*



The last example undermines what was described and concluded in the previous section. First, it demonstrates that tempo-adjusted life expectancy can be interpreted as the average of hypothetical life expectancies of all cohorts living during the observed period, assuming that all currently saved deaths occur instantly in the next period. Second, the fact that tempo-adjusted life expectancy remains higher for population A in the first periods after the changes in mortality fits in with the mortality conditions of those cohorts alive in these periods. Thus, tempo-adjusted life expectancy seems to be the more appropriate indicator for period mortality conditions in light of the practical purpose of a period measure as described at the beginning of this paper. Third, it becomes clear again that conventional life expectancy must be seen as a specific projection of cohort life expectancy of those born in year 2 rather than being a valuable indicator for period mortality.

Consequently, this example shows that even in a situation in which mortality changes occur according to the conventional life table assumption, tempo-adjusted life expectancy provides not only more appropriate information on period mortality conditions, but, more importantly, does not lead to disturbing paradoxes such as those provided by conventional life expectancy in the case where mortality changes according to the Bongaarts/Feeney assumption.

Figure 9 – *Conventional and tempo-adjusted period life expectancy for population A and population B assuming constant q_x (conventional life table assumption)*



Comparing the two scenarios reveals that the Bongaarts/Feeney assumption can be considered as the most pessimistic extreme of what could happen to deaths that are postponed in a specific period. We could similarly think of an alternative, most optimistic scenario in which all postponed deaths survive until the highest possible age. Therefore, we modelled a scenario in which the mortality of populations A and B evolves according to this most optimistic case (results not shown here, the corresponding graphs are available from the authors). Even in this scenario, which produces opposite of the Bongaarts/Feeney assumption, tempo-adjusted life expectancy does not provide a reversed picture of the survival of cohorts as does conventional life expectancy in the case when mortality changes according to the Bongaarts/Feeney assumption. In this scenario, too, tempo-adjusted life expectancy yields the average life expectancy of all hypothetical cohorts alive in year 2. Furthermore, conventional life expectancy produces a picture of life expectancy trends that is even more favourable than the trends in lagged cohort life expectancies, *i.e.* a steeper increase in life expectancy and an earlier achievement of the new life expectancy level. This highlights the distortions tempo effects can create when conventional period life expectancy is used in order to track and evaluate trends in mortality.

6. TEMPO-ADJUSTED LIFE EXPECTANCY 2001/2005 FOR 41 COUNTRIES

In the previous sections we concluded that tempo-adjusted life expectancy is a more appropriate measure for period mortality than conventional life expectancy. In this section we show that mortality tempo-adjustment is not just a technical issue but can have severe impacts on the interpretation of period mortality, above all regarding the analysis of life expectancy differentials between populations or sub-populations. Luy (2006, 2008) has already shown this using mortality differences between eastern and western Germany. Once life expectancy is adjusted for tempo effects, the differences between eastern and western Germany do not decrease immediately after unification, and ten years later they are still higher when compared to the differences in conventional life expectancy. Thus, tempo-adjusted life expectancy can draw a very different picture of mortality differentials than conventional life expectancy. We extended the empirical application of mortality tempo-adjustment and estimated tempo-adjusted life expectancy for the years 2001-2005 (average of the estimates for these five calendar years) for 41 countries with sufficient mortality data. Most of the data used stem from the Human Mortality Database⁵. Only the estimates for Greece and Romania are based on data from the Eurostat Database⁶.

Tempo-adjusted life expectancy was estimated by using the method proposed by Bongaarts and Feeney (2002), using a series of sex- and age-specific death rates from 1960 to 2005 and applying the shifting Gompertz mortality change model for estimating the tempo bias (a detailed description of this procedure can be found in Bongaarts and Feeney, 2002, and Luy, 2006)⁷. As proposed by Bongaarts and Feeney (2006), estimates for tempo-adjusted life expectancy at birth assume no tempo effects below age 30. The resulting estimates for tempo-adjusted life expectancy differ only minimally from estimates of tempo effects based on annual changes in the TMR, which is an alternative way of estimating tempo-adjusted life expectancy (see Bongaarts and Feeney, 2003, 2006). Since the data necessary to determine the TMR is available for only a few countries, we used the method based on the shifting Gompertz mortality change model for all 41 countries⁸.

⁵ Human Mortality Database: <http://www.mortality.org>, all files downloaded on July 31, 2009.

⁶ Eurostat Database: <http://epp.eurostat.ec.europa.eu/portal/page/portal/population/data/database>.

⁷ Exceptions regarding the used time series because of data availability are New Zealand Non-Maori (1960-2003), Australia (1960-2004), Greece (1961-2005), Romania (1968-2005), Taiwan (1970-2005), Israel (1983-2005) and Slovenia 1983-2005).

⁸ Unlike the estimation procedures of Bongaarts and Feeney (2002) and Luy (2006), we applied the estimated tempo bias directly to the given conventional life expectancy. The iteration procedure of the method based on the shifting Gompertz mortality change model

Tables 3 and 4 show the results for females and males, respectively. The first column presents the values for conventional life expectancy at birth, the second column the corresponding estimates for tempo-adjusted life expectancy. The next column gives the difference between conventional and tempo-adjusted life expectancy. In most cases this difference is positive, meaning that improvements in mortality conditions lead to tempo effects which bias conventional life expectancy upwards. However, there are some eastern European countries, such as Russia or Ukraine, where mortality increased during the last decades and thus tempo distortions caused the opposite effect. The last two columns contain the ranks of the countries according to conventional and tempo-adjusted life expectancy, respectively. The countries are ordered by the absolute amount of tempo effects, *i.e.* by the difference between conventional and tempo-adjusted life expectancy, with the country with the highest mortality tempo effects being on the top and the country with the lowest tempo effects being on the bottom of the table. The difference between the highest and lowest life expectancy and the standard deviation of the corresponding estimates for conventional and tempo-adjusted life expectancy reveal that among both sexes the differences between countries decrease once life expectancy is adjusted for tempo effects⁹.

Among females, Japan is the country with the highest conventional life expectancy (see Table 3). Tempo-adjusted life expectancy is three years lower than conventional life expectancy for Japanese females. But despite these significant tempo effects, Japanese women also show the highest tempo-adjusted life expectancy. However, the difference between Japan and the next country in the ranking of life expectancy decreases considerably.

According to conventional life expectancy, Japanese females have an advantage of 1.97 years over France on rank 2. According to tempo-adjusted life expectancy, this advantage is only 0.66 years over Switzerland, which takes second place from France in the corresponding ranking. After Japan,

requires an initial assumption for the tempo bias in the first year of the used time series, *i.e.* in the case of our estimates the year 1960. In order to eliminate the sensitivity to the initial condition of the estimates for the tempo bias for the years 2001-2005, we used a tempo bias of 0, 1 or 2 years as the initial condition, depending on the trends in conventional period life expectancy between 1960 and 1970. That is, in the case of stalled life expectancy between 1960 and 1970, we assumed no tempo bias as the initial condition, in the case of steep rising life expectancy we assumed a tempo bias of 2 years, and for the cases in between we assumed a tempo bias of 1 year in 1960. In cases of decreasing life expectancy we used the equivalent negative values.

⁹ Compared to conventional life expectancy the maximum differences decrease from 13.16 to 9.19 years among females and from 20.19 to 16.11 years among males, the standard deviation decreases from 2.91 to 2.34 among females and from 4.98 to 3.84 among males.

CONVENTIONAL VERSUS TEMPO-ADJUSTED LIFE EXPECTANCY

Table 3 – *Conventional life expectancy e_0 and tempo-adjusted life expectancy e_0^* for 41 countries, females 2001-2005, no tempo effects below age 30*

	e_0	e_0^*	Difference	Rank	
				e_0	e_0^*
Japan	85.28	82.29	2.99	1	1
Eastern Germany	81.37	78.61	2.76	19	25
Taiwan	80.14	77.55	2.58	26	28
Italy	83.23	81.02	2.21	4	7
Australia	82.97	80.76	2.21	6	9
Ireland	80.62	78.55	2.07	23	26
Austria	81.85	79.78	2.06	13	17
Israel	81.60	79.63	1.98	14	19
Slovenia	80.55	78.62	1.93	25	24
France	83.31	81.40	1.91	2	3
Western Germany	81.58	79.73	1.86	16	18
Spain	83.21	81.36	1.85	5	4
Finland	81.90	80.04	1.85	12	15
New Zealand (Non-Maori)	81.93	80.09	1.84	11	13
Portugal	80.93	79.10	1.83	22	22
Poland	78.89	77.08	1.81	30	31
England & Wales	80.95	79.24	1.71	21	20
Czech Republic	78.89	77.19	1.69	31	30
Switzerland	83.31	81.63	1.67	3	2
Belgium	81.46	79.87	1.59	17	16
Iceland	82.82	81.23	1.59	7	5
Scotland	79.12	77.54	1.58	29	29
Hungary	76.89	75.35	1.54	35	36
Greece	81.59	80.07	1.51	15	14
Northern Ireland	80.60	79.10	1.50	24	21
Canada	82.23	80.83	1.41	9	8
Estonia	77.38	76.01	1.37	34	34
Norway	81.95	80.66	1.29	10	10
Denmark	79.76	78.50	1.26	28	27
Sweden	82.39	81.16	1.23	8	6
Slovakia	77.88	76.73	1.15	32	33
Luxembourg	81.43	80.31	1.13	18	11
USA	80.01	78.93	1.09	27	23
Romania	75.08	74.07	1.01	38	39
Russian Federation	72.12	73.09	-0.97	41	41
Latvia	76.28	75.38	0.90	36	35
Netherlands	81.07	80.22	0.85	20	12
Bulgaria	75.88	75.15	0.73	37	38
Lithuania	77.51	76.79	0.72	33	32
Belarus	74.69	75.33	-0.64	39	37
Ukraine	73.56	74.06	-0.49	40	40

France and Switzerland, Italy ranks fourth in conventional life expectancy, but in the ranking of tempo-adjusted life expectancy, Italy falls further behind Spain, Iceland and Sweden. There are some further cases showing that the effects of tempo-adjustment are more significant than just causing a change of the position of countries in the corresponding rankings of life expectancy. For instance, according to the conventional values, eastern German females have a 1.36 years higher life expectancy than U.S. women. However, after tempo-adjustment the life expectancy of U.S. women exceeds that of eastern German women by 0.32 years. Thus, this example shows that paradoxes such as those demonstrated in the previous section with model populations A and B (where population B shows the higher conventional period life expectancy although each cohort of population A lives longer than the corresponding cohort of population B) can exist in empirical reality. Given the different histories and structural compositions of the U.S and the eastern German population, it becomes apparent that tempo-adjusted life expectancy can provide a completely different result regarding mortality differentials and consequently can lead to very different conclusions regarding the determinants of mortality. Besides Italy and eastern Germany, the women from Australia, Ireland, Austria, Israel and Finland are the “losers” in the ranking of tempo-adjusted life expectancy. On the other side, the “winners” among females are the Netherlands (moving up from rank 20 according to conventional life expectancy to rank 12 according to tempo-adjusted life expectancy) and Luxembourg (moving up from 18 to rank 11).

Among males the first two places in the life expectancy rankings remain unchanged: Iceland is ranked first, followed by Japan (see Table 4). Contrary to the situation among women, the difference between these two countries increases from 0.56 years to 1.27 years once life expectancy is adjusted for tempo effects. Among males, tempo-adjustment also provides a very different picture of mortality differentials. For instance, according to the conventional estimation method, life expectancy of New Zealand’s males (Non-Maori) exceeds those of men from the Netherlands by 1.04 years. After tempo-adjustment, Dutch males show a slightly higher life expectancy with an advantage of 0.13 years. Also interesting are the effects of tempo-adjustment on life expectancy differences between East European countries. According to the conventional values, Latvia’s life expectancy exceeds that of Russia by 6.69 years. According to tempo-adjusted life expectancy, however, the difference is more than three years smaller. Among males, the “losers” in the ranking of life expectancy after tempo-adjustment – falling three or more ranks – are Australia, New Zealand (Non-Maori), Austria, Italy, Ireland and England & Wales. The “winners” are Greece (moving up

CONVENTIONAL VERSUS TEMPO-ADJUSTED LIFE EXPECTANCY

Table 4 – *Conventional life expectancy e_0 and tempo-adjusted life expectancy e_0^* for 41 countries, males 2001-2005, no tempo effects below age 30*

	e_0	e_0^*	Difference	Rank	
				e_0	e_0^*
Australia	78.00	74.74	3.27	4	10
New Zealand (Non-Maori)	77.46	74.58	2.88	7	13
Eastern Germany	74.89	72.10	2.79	24	26
Austria	76.09	73.32	2.77	17	21
Italy	77.50	74.75	2.75	6	9
Finland	75.08	72.34	2.74	23	24
Ireland	75.67	73.06	2.61	19	22
England & Wales	76.56	73.97	2.59	11	14
Russian Federation	58.75	61.32	-2.57	41	41
Slovenia	72.98	70.46	2.52	29	29
France	76.13	73.64	2.49	16	17
Canada	77.39	74.91	2.48	9	7
Switzerland	78.05	75.58	2.47	3	4
Western Germany	76.15	73.70	2.45	15	16
Belarus	62.72	65.09	-2.37	39	38
Northern Ireland	75.72	73.47	2.25	18	18
USA	74.82	72.58	2.24	25	23
Japan	78.38	76.16	2.22	2	2
Taiwan	74.29	72.09	2.20	26	27
Norway	76.98	74.82	2.16	10	8
Czech Republic	72.34	70.21	2.14	30	30
Belgium	75.51	73.38	2.12	20	20
Scotland	73.90	71.78	2.12	28	28
Ukraine	62.02	64.07	-2.05	40	40
Sweden	77.98	75.95	2.03	5	3
Portugal	74.28	72.28	2.00	27	25
Israel	77.43	75.57	1.86	8	5
Spain	76.47	74.61	1.86	12	12
Denmark	75.17	73.43	1.73	22	19
Netherlands	76.42	74.71	1.70	14	11
Luxembourg	75.39	73.79	1.60	21	15
Poland	70.43	68.83	1.60	31	31
Iceland	78.94	77.43	1.51	1	1
Greece	76.44	75.12	1.33	13	6
Hungary	68.47	67.17	1.30	34	35
Slovakia	69.92	68.74	1.18	32	32
Estonia	65.98	65.28	0.70	37	37
Latvia	65.44	64.77	0.68	38	39
Lithuania	66.02	66.43	-0.40	36	36
Romania	67.82	67.49	0.33	35	34
Bulgaria	68.86	68.66	0.20	33	33

from rank 13 according to conventional life expectancy to rank 6 according to tempo-adjusted life expectancy), Luxembourg (moving up from 21 to rank 15), the Netherlands (moving up from 14 to rank 11) and Denmark (moving up from 22 to rank 19).

7. CONCLUSIONS

Tempo effects exist and occur as do age composition effects. This was shown with the empirical TMR for West Germany from 1970 to 2005. We have shown that both conventional and tempo-adjusted life expectancy standardize for these tempo effects. However, the two measures differ in the way they standardize. Conventional life expectancy deals with tempo effect-caused postponed deaths as if there were no tempo effects, whereas tempo-adjusted life expectancy takes tempo effects explicitly into account. These preconditions raise the questions about the purposes of period measures and how these purposes are addressed by the two standardization procedures. In our opinion, period indicators should measure only period conditions including the effects of changes which are independent of past and future assumptions (technical purpose). Furthermore, a period measure of mortality should reflect the current mortality conditions of the real cohorts in order to allow conclusions for political or medical interventions (practical purpose).

In light of these demands, our theoretical (model) examples have shown that tempo effects can lead to severe distortions of information about the current mortality conditions of a population when conventional life expectancy is used as an indicator for period mortality: *(i)* conventional period life expectancy can reach a level that no cohort ever achieves, *(ii)* conventional period life expectancy can decrease although each subsequent cohort experiences an increase in life expectancy (thus, conventional period life expectancy indicates a mortality increase that is not experienced by any cohort), and *(iii)* conventional period life expectancy can provide a lower level for a population A as compared to a population B, although each cohort of population A has a higher life expectancy than the corresponding cohort of population B (thus, conventional period life expectancy indicates a higher mortality of a population in which every cohort lives longer than the corresponding cohort of the other population). Although the models where these paradoxes appeared are based on the assumption that mortality changes take place as stated by the (most conservative) Bongaarts/Feeney assumption, we think there should be no theoretical situation in which such paradoxes can occur. The examples where mortality changes have been modelled to follow the conventional life table assumption as well as the most

optimistic scenario (all postponed deaths surviving until the highest possible age) have shown that tempo-adjusted life expectancy is free of such paradoxical and misleading results.

The examples revealed that paradoxes provided by conventional life expectancy arise when the mortality changes in the cohorts alive in the period of observation are less favourable than stated by the conventional life table assumption. Such paradoxes cannot happen to tempo-adjusted life expectancy since this measure is based on the most conservative assumption that all postponed deaths immediately die in the next period. Additionally, this assumption is automatically identical for all populations regardless of their level of mortality changes. Thus, tempo-adjusted life expectancy uniformly standardizes for tempo effects in all populations. This does not apply to the assumptions behind conventional period life expectancy.

From the findings presented in this paper we conclude that tempo-adjusted period life expectancy does fulfil our demands on a period measure and is an adequate way of standardizing period mortality conditions for the compositional effects of age and postponement of deaths. In Section 6 we showed with empirical data that mortality tempo effects can cause conventional life expectancy to be biased by more than three years. Thus, tempo effects can lead to distortions which are strong enough to severely influence the estimation of life expectancy differences between populations and sub-populations and consequently also the analysis of determinants of mortality differentials. These results suggest that we can expect tempo effects to similarly affect the empirical analysis of most mortality differentials, including the opening and the recent closing of the mortality gap between women and men in the developed world, the linear increase in record life expectancy at birth described by Oeppen and Vaupel (2002), the increasing mortality gap between eastern and western Europe, and other similar phenomena.

The discussion about tempo effects is mainly a discussion about the definition and interpretation of period indicators. The question is not whether tempo effects exist. The question is whether they have to be seen as distortions that have to be taken into account. We argue that period life expectancy as an indicator for period mortality conditions must have a meaning for the currently living cohorts. This is a necessary precondition since period life expectancy is used as an indicator for the current health conditions of a population, to evaluate the effectiveness of specific health measures, or to evaluate the impact of specific factors on mortality. If the measure we use does not reflect the mortality of the real population we cannot draw the desired conclusions. Most papers criticizing tempo-adjustment of life expectancy focus on aspects related to the specific

adjustment formulae rather than discussing the practical importance of tempo distortions (see Luy 2006, 2008). We hope that our alternative way of looking at the assumptions behind conventional and tempo-adjusted life expectancy might help lead this discussion in a direction that does justice to the tempo approach of Bongaarts and Feeney regarding its application in the analysis of period mortality.

Acknowledgements

We thank the colleagues at the Vienna Institute of Demography for stimulating discussions, John Bongaarts and Mark Hayward for valuable comments on earlier versions of this paper that have been presented at the PAA 2009 Annual Meeting of the Population Association of America in Detroit, USA and at the XXVI IUSSP International Population Conference 2009 in Marrakech, Morocco, as well as Richard Bates for language editing. Furthermore, we are grateful for helpful comments and suggestions received from two anonymous reviewers. This work was supported through grant P20649-G14 from the FWF Austrian Science Fund.

References

- BARBI E., BONGAARTS J., VAUPEL J.W. (eds.) (2008), *How long do we live? Demographic models and reflections on tempo effects*, Springer, Leipzig. (URL: <http://www.demogr.mpg.de/books/drm/005/>)
- BECKER K. (1869), “Preussische Sterbetafeln, berechnet auf Grund der Sterblichkeit in den 6 Jahren 1859-64, auch Vergleich mit fremden Sterbetafeln”, *Zeitschrift des Königlich Sächsischen Statistischen Bureaus*, 9(17), 126-144.
- BECKER K. (1874), *Zur Berechnung von Sterbetafeln an die Bevölkerungsstatistik zu stellende Anforderungen*, Verlag des Königlich statistischen Bureaus, Berlin.
- BONGAARTS J. (2005), “Five period measures of longevity”, *Demographic Research*, 13(21), 547-558. (URL: <http://www.demographic-research.org/Volumes/Vol13/21/13-21.pdf>)
- BONGAARTS J., FEENEY G. (2002), “How long do we live?”, *Population and Development Review*, 28(1), 13-29.

- BONGAARTS J., FEENEY G. (2003), "Estimating mean lifetime", *Proceedings of the National Academy of Sciences*, 100(23), 13127-13133.
- BONGAARTS J., FEENEY G. (2006), "The tempo and quantum of life cycle events", *Vienna Yearbook of Population Research*, 115-151.
(URL: http://hw.oeaw.ac.at/0xc1aa500d_0x00191ce7)
- BROUARD N. (1982), "Structure et dynamique des populations. La pyramide des années à vivre, aspects nationaux et exemples régionaux", *Espaces, Populations, Sociétés*, 2(14-15), 157-168.
- GOLDSTEIN J.R. (2006), "Found in translation? A cohort perspective on tempo-adjusted life expectancy", *Demographic Research*, 14(5), 71-84.
(URL: <http://www.demographic-research.org/Volumes/Vol14/5/14-5.pdf>)
- 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.
- GUILLOT M. (2006), "Tempo effects in mortality: an appraisal", *Demographic Research*, 14(1), 1-26.
(URL: <http://www.demographic-research.org/volumes/vol14/1/14-1.pdf>)
- LUY M. (2006), "Mortality tempo-adjustment: an empirical application", *Demographic Research*, 15(21), 561-590.
(URL: <http://www.demographic-research.org/Volumes/Vol15/21/15-21.pdf>)
- LUY M. (2008), "Mortality tempo-adjustment: theoretical considerations and an empirical application", in BARBI E., BONGAARTS J., VAUPEL J.W. (eds.), *How long do we live? Demographic models and reflections on tempo effects*, Springer, Leipzig, 203-233.
(URL: <http://www.demogr.mpg.de/books/drm/005/11.pdf>)
- OEPPEN J., VAUPEL J.W. (2002), "Broken limits to life expectancy", *Science*, 96(5570), 1029-1031.
(URL: <http://www.sciencemag.org/cgi/content/full/296/5570/1029>)
- RODRÍGUEZ G. (2006), "Demographic translation and tempo effects: an accelerated failure time perspective", *Demographic Research*, 14(6), 85-110.
(URL: <http://www.demographic-research.org/Volumes/Vol14/6/14-6.pdf>)
- SARDON J.-P. (1993), "Un indicateur conjoncturel de mortalité: l'exemple de la France", *Population*, 48(2), 347-368.
- SARDON J.-P. (1994), "A period measure of mortality. The example of France", *Population: An English Selection*, 6, 131-158.

- STATISTISCHES BUNDESAMT (2006), *Generationensterbetafeln für Deutschland. Modellrechnungen für die Geburtsjahrgänge 1871-2004*, Statistisches Bundesamt, Wiesbaden.
(URL: <https://www-ec.destatis.de/csp/shop/3922sfg/bpm.html.cms.cBroker.cls?cmspath=struktu,vollanzeige.csp&ID=1018268>)
- WARD M.P., BUTZ W.P. (1980), “Completed fertility and its timing”, *Journal of Political Economy*, 88(5), 917-940.
- ZEUNER G. (1869), *Abhandlung aus der mathematischen Statistik*, Arthur Felix, Leipzig.
- ZEUNER G. (1894), “Neue Sterblichkeitstafeln für die Gesamtbevölkerung des Königreichs Sachsen. Nach den Erhebungen und Berechnungen des Königlich Sächsischen Statistischen Bureaus”, *Zeitschrift des Königlich Sächsischen Statistischen Bureaus*, 40, 13-50.
- ZEUNER G. (1903), “Neue Sterblichkeitstafeln für die Gesamtbevölkerung des Königreichs Sachsen. Nach den Erhebungen und Berechnungen des Königlich Sächsischen Statistischen Bureaus”, *Zeitschrift des Königlich Sächsischen Statistischen Bureaus*, 49, 76-92.