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

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Abstract

This paper discusses the question: which characteristics are appropriate for a measure of period mortality and how are these characteristics met in conventional and tempo-adjusted life expectancy? According to our perspective, a period mortality measure should include exclusively the current mortality and should enable comparison of period-specific mortality conditions of two populations or the changes between two periods without depending on past or future trends. By using a simple population model, we show that the conventional period life expectancy does not meet these demands since it includes specific assumptions regarding future mortality, which differ between different populations and at the end can lead to paradoxes disturbing its practical purpose. Tempo-adjusted life expectancy, however, is free of these compositional effects and thus enables the analysis and comparison of pure period-specific mortality conditions. From these considerations we also derive an interpretable definition for tempo-adjusted life expectancy. We suspect that this lack of definition could be a major reason 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 showing that tempo effects and their adjustment are not only a technical issue but can have significant impacts on the interpretation of period mortality.

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1. Introduction

Life expectancy still is the most common measure for period mortality. Compared to other mortality measures life expectancy has the advantage of a distinct meaning with an easy 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 effects of mortality differences or changes in specific age groups or causes of death on overall mortality of a population. These specific characteristics make life expectancy to the most important mortality measure for policy purposes.

Recently, a new discussion around period life expectancy arose among demographers. In a series of papers Bongaarts and Feeney (2002, 2003, 2006) suggested to use tempo-adjusted life expectancy for period analysis because conventional period life expectancy is affected by tempo distortions. In contrary to the discussion around mortality tempo adjustment of the last years (see 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 period mortality of two populations experiencing different changes in (age-specific) mortality. We will analyze these questions with a simple model population consisting of only four age groups. Nevertheless, the results are of high importance for every kind of empirical mortality analysis comparing different populations, above all because the relations are represented in discrete time as it occurs in practical mortality analysis. The reason for choosing this simple population model is that it allows to following postponed deaths regarding their future occurrence easily. As will be shown, this is 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 following paper we explain two main conclusions of our reflections: (i) we will show a technical aspect behind general 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 will 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 can not. We are aware that other scholars might see the meaning of the technical and practical purposes of a period mortality measure different from our perspective. However, following our considerations we will derive an interpretable definition for tempo-adjusted life expectancy. Such a definition is still missing in the demographic literature and maybe 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 will demonstrate that tempo effects and their adjustment can have significant impacts on the interpretation of period mortality.

2. Practical and technical purposes of a period measure: demands on period life expectancy

Our perspective is driven by the demand that – in order to fulfill the just mentioned purposes – a period mortality measure should include only the current mortality conditions, i.e. the mortality conditions of the analyzed calendar years. A period measure for mortality should **enable 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" follows that the calculated value itself is not expected to have a specific meaning for any cohort since period life expectancy contains (approximately) 1 % of the cohort mortality of 100 different cohorts. We know that no cohort will ever experience the age-specific mortality schedule of 100 different cohorts being in 100 different ages at a certain moment of time. This is why period life expectancy is referring 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 analyzed period. 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, and this information should enable 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) in order to having a basis for necessary or possible measures to improve survival conditions (of 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 current period mortality conditions measured through age-specific death rates.

The **technical purpose** of a period measure is to standardize the current demographic conditions for all compositional effects disturbing its practical purpose. We will see that both, conventional and tempo-adjusted life expectancy standardize for such effects, however, in a different manner. Since, as we just mentioned, period measures are hypothetical by their pure nature, it is not possible to conclude that one way of standardization is correct and the other is incorrect. But it is possible to think about what consequences the two ways of standardization have for the calculated parameter 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 side, 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 being 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. However, they should not affect the period value itself in a numerical definable way.

In the subsequent sections we will 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 whereas 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 whereas 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 to follow easily 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 500 and constant age-specific mortality conditions (probabilities of dying). According to these mortality conditions, 100 individuals die at age 0, 50 at age 1, 250 at age 2, and the remaining 100 survivors die at age 3. “Constant conditions” means that these case numbers occur identically for each cohort and in each single calendar year period. Note that our calculations of 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 being free of tempo effects, in contrast to the typical estimation from age-specific death rates. Our models will show, however, that the birth year method contains tempo effects as 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 of younger cohorts to die later on average than their counterparts of older cohorts. A logical consequence of such changes is that the deaths of younger cohorts are postponed to a later moment in time. 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) which summarizes the period-specific death rates of all currently living cohorts (number of deaths of a specific cohort in a specific period divided by the original number of cohort members at the moment of birth, see Sardon 1993, 1994). The TMR is the equivalent to the fertility measure “timing index” (Butz and Ward 1980). Like the timing index in the case of fertility, the TMR equals unity 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 every developed country since many decades. These empirical values for the TMR show that some deaths are “missing” in the period perspective. However, in the life table the quantum of mortality (and thus the TMR) is one since all 100,000 births 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 a new view on the differences between conventional and tempo-adjusted life expectancy. Interestingly, this view reveals that both, conventional and tempo-adjusted calculation standardize for the tempo effect-caused missing of period deaths. **The difference between conventional and tempo-adjusted life expectancy can be seen as a consequence of the way how the missing deaths are redistributed inside the life table, or, in other words, how tempo effects are standardized for.** How 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 modeling is driven by the idea to reconstruct 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 cover always two calendar years. For simplicity, in the following text some times only the first of these two years is given.)

We assume that the constant conditions as given in table 1 remain unchanged until year 1. In year 2 (period 2/3) 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 90 at age 0, 45 at age 1, 225 at age 2, and 90 at age 3. Compared to the situation before, 50 deaths (10 percent of 500) have been saved: 10 at age 0, 5 at age 1, 25 at age 2 and 10 at age 3 (here we assume a shift to the now reachable age 4; note that assuming a constant highest age of 3 would not affect the basic conclusions, however). This shift of deaths leads to an “incomplete” pattern of death numbers in year 2. Calculating the Total Mortality Rate (TMR) for this year provides 0.9 reflecting the relative amount of postponed deaths due to the survival improvement. As has been 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 (period 2/3). Thus, we use the probabilities of dying q(x) as given in the years 2 and 3 and use them for constructing a period life table. Since we know that in this life table the TMR will equal 1.0 we can conclude that the 50 missing deaths in the period 2/3 must have been redistributed inside the corresponding period life table. In the following we will reconstruct this redistribution according to the conventional and the tempo-adjusted methodology, respectively. The goal is to visualize the consequences of the corresponding assumption for the life table cohort born in year 2, i.e. the "hypothetical" cohort to which the estimated life expectancy refers to, as well as of all other cohorts living in the years 2 and 3 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. **The basic assumption of the conventional life table is that the current probabilities of dying q(x) remain constant in all future years.** As a consequence, the hypothetical cohort of newborns will experience exactly these probabilities of dying during its life course. Moreover, from the assumption of constant q(x) follows that the 50 postponed deaths are redistributed into higher ages and thus into the following years according to the current (and from now on constant) q(x) schedule. The Lexis graph in figure 2 shows that according to the conventional life table assumption this process takes the whole lifetime of the modeled 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 saved deaths. 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 amount of postponed deaths in the analyzed period. The latter follows from the fact that the probabilities of dying q(x) are based on mortality conditions leading the TMR to being below unity. 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 future mortality as will be shown in the subsequent section. However, already at this point we can conclude that changing mortality should be seen as a compositional effect that a period measure should adjust for.

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 important to note 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 on 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 did extinct. **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 see that in principle 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 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.

Up to this point it is, however, 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 have to look at the assumptions behind tempo-adjusted life expectancy in a similar manner. Tempo-adjusted life expectancy is based on a different assumption regarding the future destiny of the postponed deaths. The basic assumption here is that all postponed deaths occur in the next calendar year as demonstrated in figure 3. This assumption could be seen as maximum conservative, however, with the consequence that the assumed future trends result in constant period conditions for the hypothetical population. This can 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 at unity for all future years (more details on the consequences of the Bongaarts/Feeney assumption are presented in the subsequent section). 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 since any change in mortality conditions is standardized for in a way that leads to a TMR of 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 look like. 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 (period of years 2 and 3) 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 in figure 4 the cohort life expectancies are represented at the calendar year of extinction. The corresponding birth year of these cohorts is given at the top of figure 4. (Note furthermore that due to the changes in mortality there is a lag of one calendar year between the extinction of cohorts born in the years -1 and -2 as indicated by the grey dashed line between e(0) for the cohorts -2 and -1.) 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 successive higher life expectancies.** There is no decline in life expectancy among cohorts as indicated by conventional life expectancies between years 2 (period 2/3) and 3 (period 3/4). If in an empirical application period life expectancy indicated such a decline of e(0) this would probably be interpreted as an increase (thus worsening) of mortality conditions. Figure 4 shows, however, that in this example no cohort experiences an increase of mortality as compared to the previous cohorts. On the other side, 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 being alive during year 2 are the cohorts born in year 2 (life 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 have to take into account also 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 as assumed in the conventional life table method. This can be seen in figure 5 where the same calculations are done for the case that mortality changes as assumed by the conventional way of determining life expectancy (conventional life table assumption). The graph shows that even in this case the trend of tempo-adjusted life expectancy is similar to the trend of cohort life expectancy. 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 here as well. The trend of moderately increasing tempo-adjusted life expectancy as compared to the conventional period life expectancy seems also 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 the most time of their life courses. Conventional life expectancy, on the other side, can only be interpreted as average life expectancy of currently newborns assuming that current the 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. Thus, we conclude that tempo-adjusted life expectancy is in fact the more appropriate measure for standardizing period 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 and a specific assumption regarding the future destiny of currently postponed deaths. 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 has been shown in the previous section, this does not hold for the hypothetical cohorts according to the conventional life table assumption. Conventional life expectancy rather represents a specific cohort projection for the currently newborn including specific assumptions of changing future mortality, as can be seen best in figure 5.

5. Conventional and tempo-adjusted life expectancy for populations with different changes of mortality conditions

The undesired consequences of the described assumptions behind conventional life expectancy become most apparent when we consider two populations who experience different changes of their mortality conditions. This is the typical situation demographers are always faced with when they compare different populations by means of period life expectancy. For demonstrating 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 500 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 has been modeled 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 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 as 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 double 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 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 year 2 (period 2/3). 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 not even one cohort of 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 dashed lines in figure 7. Furthermore, as has been shown in the previous sections also in this example the conventional way of calculating period life expectancy provides values that no cohort of both populations ever reaches. On the other side, tempo-adjusted life expectancy averages the life expectancies of the cohorts living during the period of changing mortality.

Finally, conventional and tempo-adjusted life expectancy for populations A and B are compared 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 cohort life expectancies between periods 5/6 and 6/7 in figure 8, i.e. between cohorts born in years 1 and 2). In this example, this crossing-over is visible in both period indicators, conventional and tempo-adjusted life expectancy (see figure 9). However, the picture drawn by tempo-adjusted life expectancy reflects better the trends of the real population where in most cohorts being alive in year 2 those of population A still experience a higher life expectancy than their counterparts of population B. Thus, the later crossing-over of tempo-adjusted life expectancy provides a better picture of the mortality conditions of the currently living cohorts than does the immediate crossing-over of conventional life expectancy.

The last example undermines what has been described and concluded in the previous chapter. First, it demonstrates again 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 change in mortality fits to the mortality conditions of those cohorts being alive in these periods. Thus, tempo-adjusted life expectancy seems to be the more appropriate indicator for period mortality conditions in the 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 the more appropriate information on period mortality conditions. Even more important is the fact that tempo-adjusted life expectancy does not lead to disturbing paradoxes as those provided by conventional life expectancy in the case where mortality changes according to the Bongaarts/Feeney assumption.

6. Tempo-adjusted life expectancy 2001/2005 for 41 countries

In the previous sections we concluded that tempo-adjusted life expectancy is the more appropriate measure for period mortality than conventional life expectancy. In this section we will 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 such an example for the case of 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 still are 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-adjusted 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 Database (www.mortality.org, all files downloaded on July 31, 2009). Only the estimates for Greece and Romania are based on data from the Eurostat Database (http://epp.eurostat.ec.europa.eu/portal/page/portal/population/data/database). Tempo-adjusted life expectancy was estimated by using the method proposed by Bongaarts and Feeney (2002), based on a series of sex- and age-specific death rates from 1960 to 2005 (exceptions: New Zealand Non-Maori 1960-2003, Australia 1960-2004, Greece 1961-2005, Romania 1968-2005, Taiwan 1970-2005, Israel and Slovenia 1983-2005). Estimates for tempo-adjusted life expectancy at birth assume no tempo effects below age 30. (In this method the annual changes in the average age at death are estimated on the basis of the period-specific shift of the Gompertz parameter β. The resulting estimates for tempo-adjusted life expectancy differ only minimally from estimates based on annual changes in the TMR. Since the data necessary to determine the TMR is available for a few countries only we used the β-method for all 41 countries.)

Tables 2 and 3 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 of mortality conditions lead to tempo effects which bias conventional life expectancy in the upward direction. However, there are some eastern European countries like 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 can be found in the last two rows of the tables. These values reveal that among both sexes the differences between countries decrease once life expectancy is adjusted for tempo effects. (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).

Among females Japan is the country with the highest conventional life expectancy and at the same time the country with the highest tempo effects (see Table 2). Tempo-adjusted life expectancy is three years lower than conventional life expectancy for Japanese females. But despite this high amount of tempo effects Japanese women show also the highest tempo-adjusted life expectancy. However, the difference to 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 the second place from France in the corresponding ranking. After Japan, France and Switzerland, Italy takes rank 4 in conventional life expectancy, but in the ranking of tempo-adjusted life expectancy Italy falls further behind Spain, Iceland and Sweden. In some cases, 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 life expectancy of U.S. women exceeds life expectancy of eastern German women by 0.32 years. Thus, this example shows that paradoxes 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) 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. Beside Italy and eastern Germany, 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 (rising from rank 20 according to conventional life expectancy to rank 12 according to tempo-adjusted life expectancy) and Luxembourg (rising from 18 to rank 11).

Among males the first two places in the life expectancy rankings remain unchanged with Iceland on the first and Japan on the second place (see Table 3). In contrary to the situation among women, the difference between these two countries increases from 0.60 years to 1.27 years once life expectancy is adjusted for tempo effects. Also among males tempo-adjustment provides a very different picture of mortality differentials. For instance, according to the conventional way of calculation, 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 the slightly higher life expectancy with an advantage of 0.13 years. Also interesting are the effects of tempo-adjustment on life expectancy differences between eastern European countries. According to the conventional values, Latvia’s life expectancy exceeds those of Russia by 6.69 years. According to tempo-adjusted life expectancy, however, the differences are 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. The "winners" are Greece (rising from rank 13 according to conventional life expectancy to rank 6 according to tempo-adjusted life expectancy), Luxembourg (rising from 21 to rank 15), the Netherlands (rising from 14 to rank 11) and Denmark (rising from 22 to rank 19).

7. Summary and conclusions

Tempo effects exist and occur as do age composition effects. This has been 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 of standardization. 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 met in the two standardization procedures. In our perspective, period indicators should measure only period conditions including effects of changes which are independent from 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 the 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 indicator for period mortality: (i) 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), (ii) conventional period life expectancy can have a level that no cohort ever reaches, and (iii) conventional period life expectancy can provide a lower level for a population A as compared to another 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 of 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 Bongaarts/Feeney assumption we think there should be no theoretical situation in which such paradoxes can occur. The examples where mortality changes have been modeled to follow the conventional life table assumption have shown that tempo-adjusted life expectancy is free of providing such paradoxical and misleading results.

From the findings presented in this paper we conclude that tempo-adjusted period life expectancy does fulfill our demands on a period measure and represents an adequate solution to standardize period mortality conditions for the compositional effects of age composition and postponement of deaths. In section 6 we showed that mortality tempo effects can lead 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. According to these results we can expect that tempo effects similarly affect the empirical analysis of most phenomena of mortality differentials like 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), or 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 and to evaluate the effectiveness of specific health measures or 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 leading this discussion in a direction that gives justice to the tempo approach of Bongaarts and Feeney regarding its application in the analysis of period mortality.

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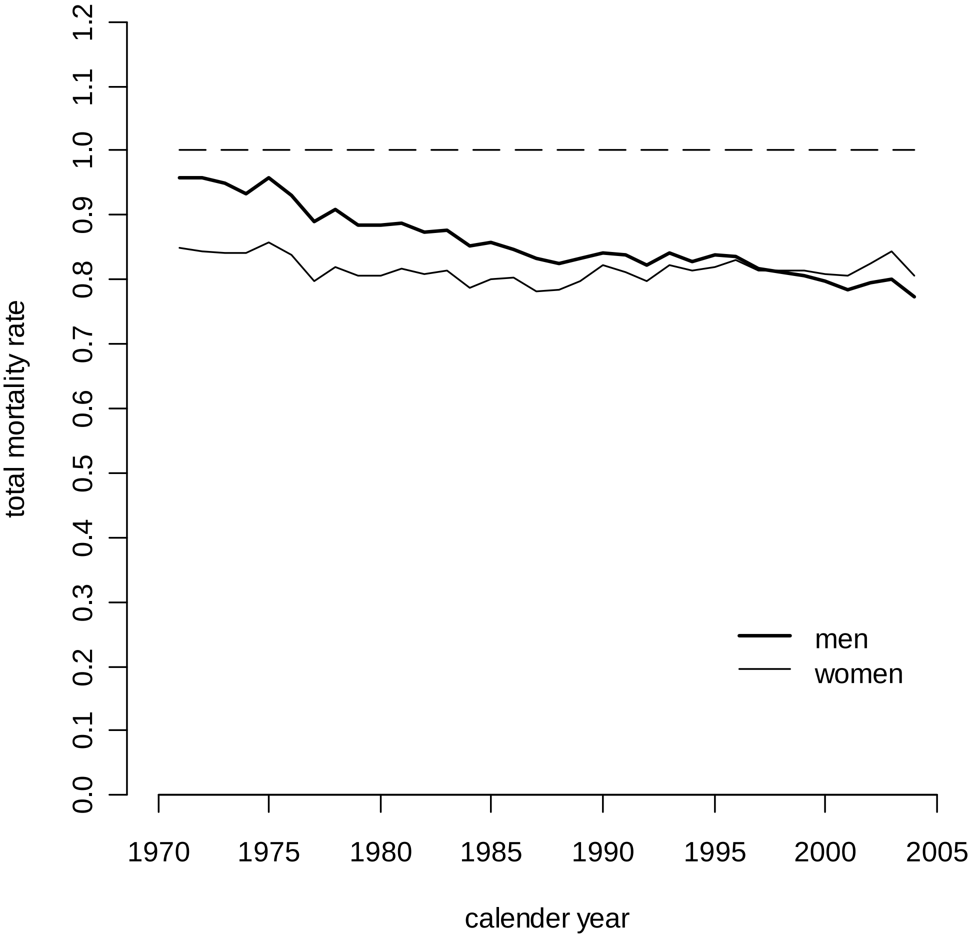
Table 1: Number of survivors at age x, deaths and resulting probabilities of dying of the model population

Age x	Survivors at age x	Deaths	q(x)
0	500	100	0.200
1	400	50	0.125
2	350	250	0.714
3	100	100	1.000

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



Source: own calculation with data of the Statistical Office of Germany (2006)

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

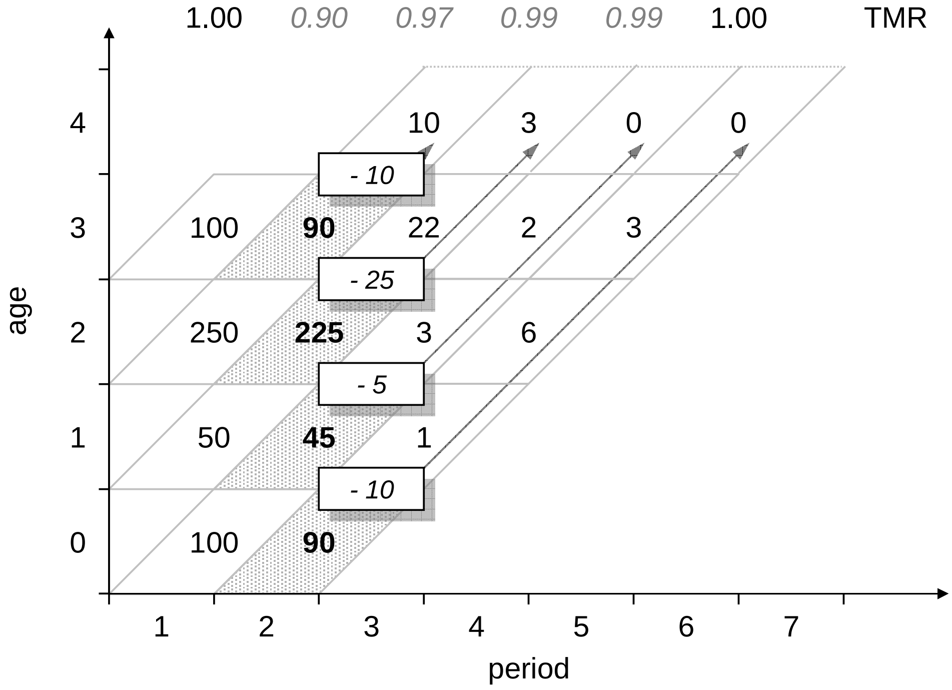


Figure 3: Redistribution of postponed deaths according to the Bongaarts/Feeney assumption

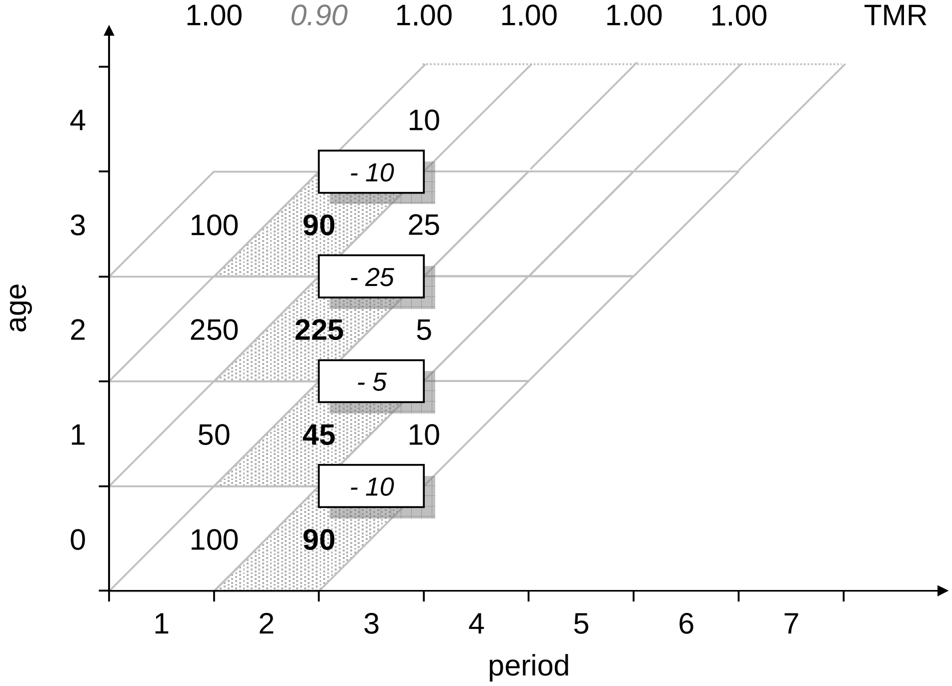


Figure 4: Trends in period, tempo-adjusted and cohort life expectancy assuming that postponed deaths occur in the next period (Bongaarts/Feeney assumption)

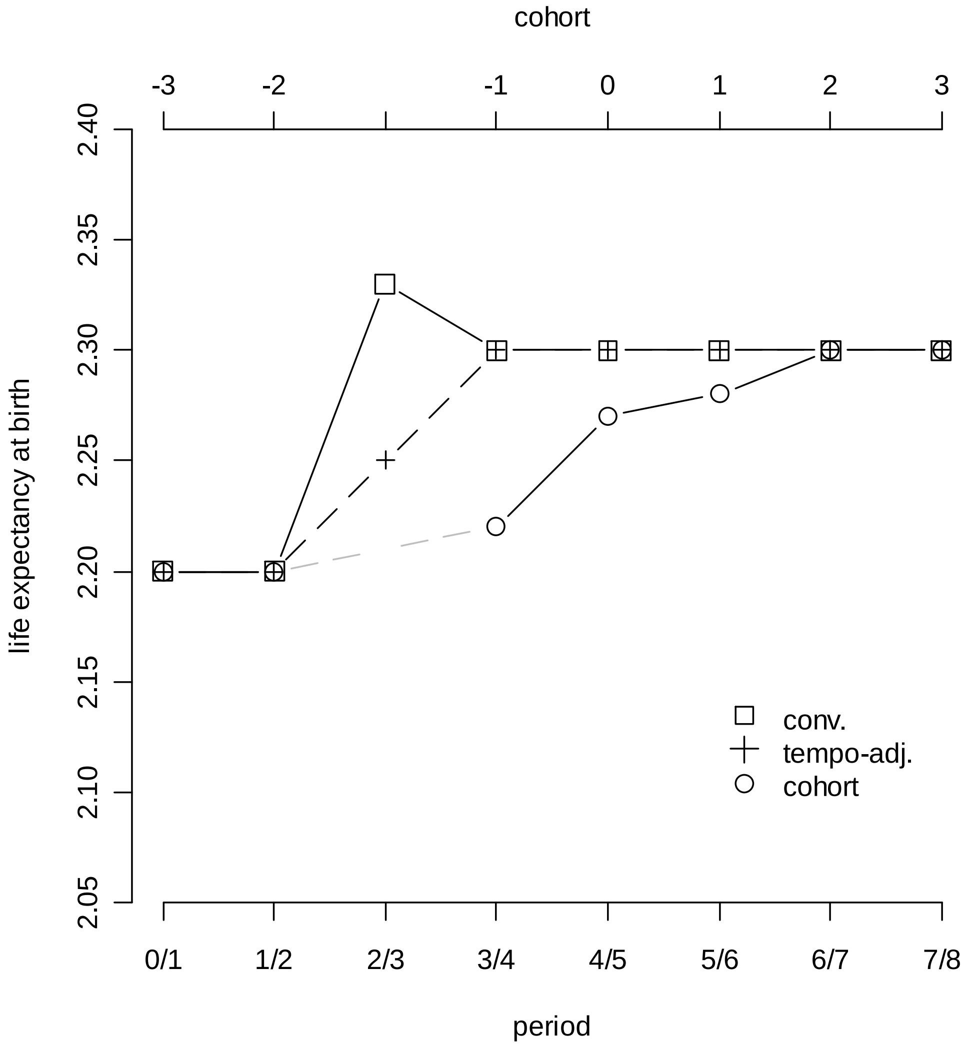


Figure 5: Trends in period, tempo-adjusted and cohort life expectancy assuming constant q(x) (conventional life table assumption)

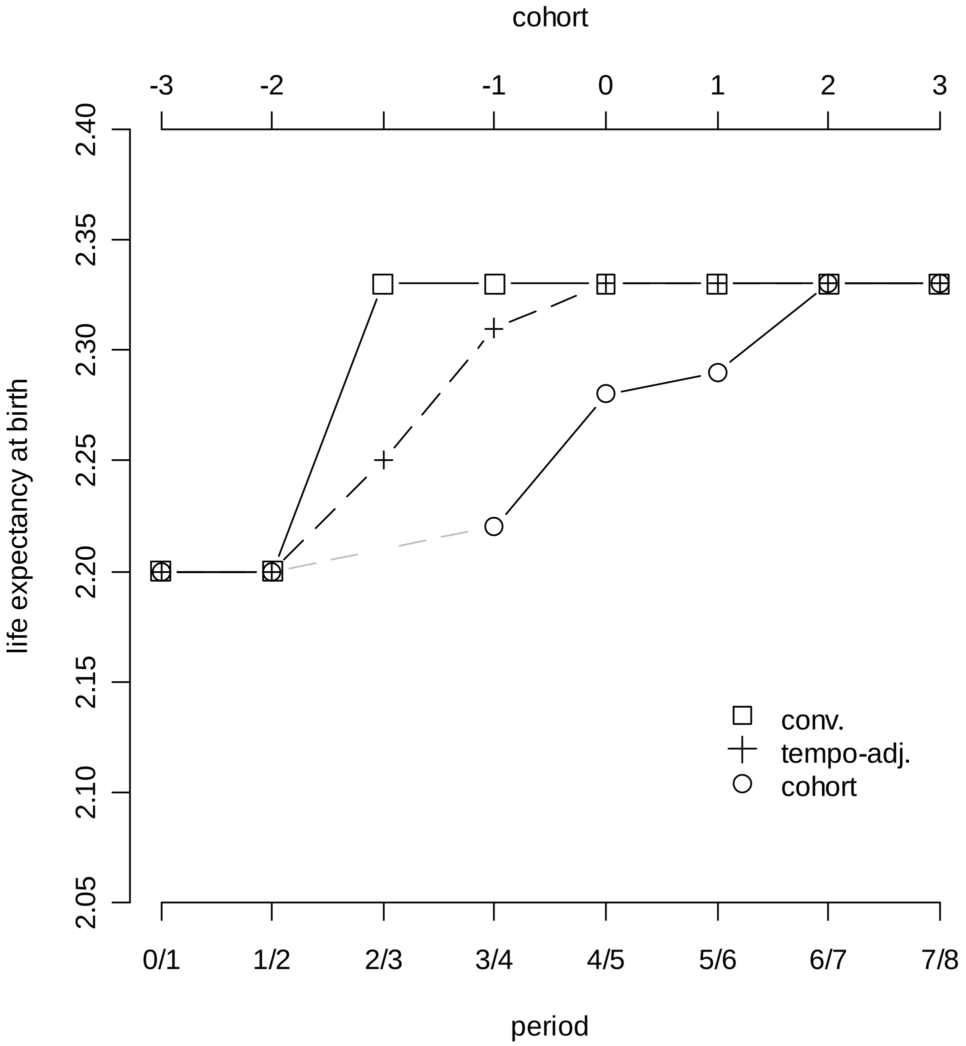


Figure 6: Cohort life expectancies for the cohorts of populations A and B assuming that postponed deaths occur in the next period (Bongaarts/Feeney assumption)

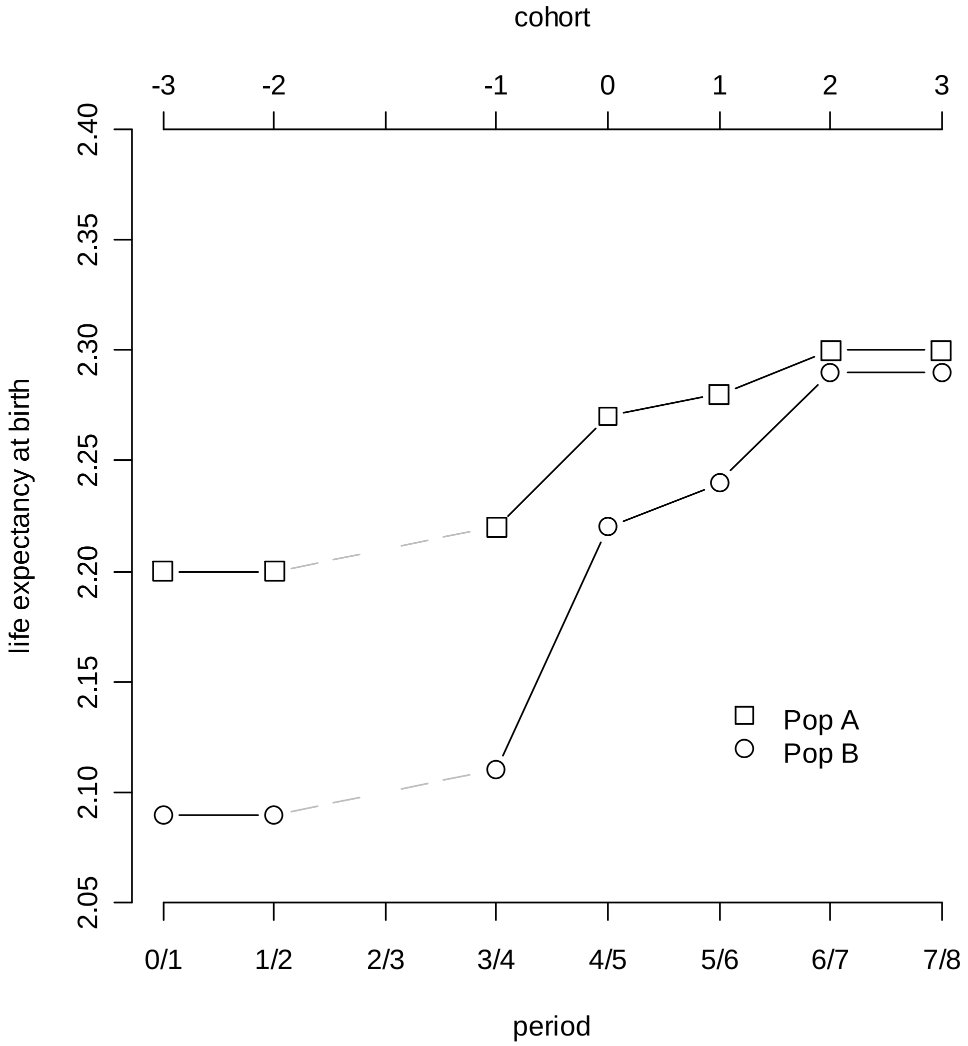


Figure 7: Conventional and tempo-adjusted period life expectancy for population A and population B assuming that postponed deaths occur in the next period (Bongaarts/Feeney assumption)

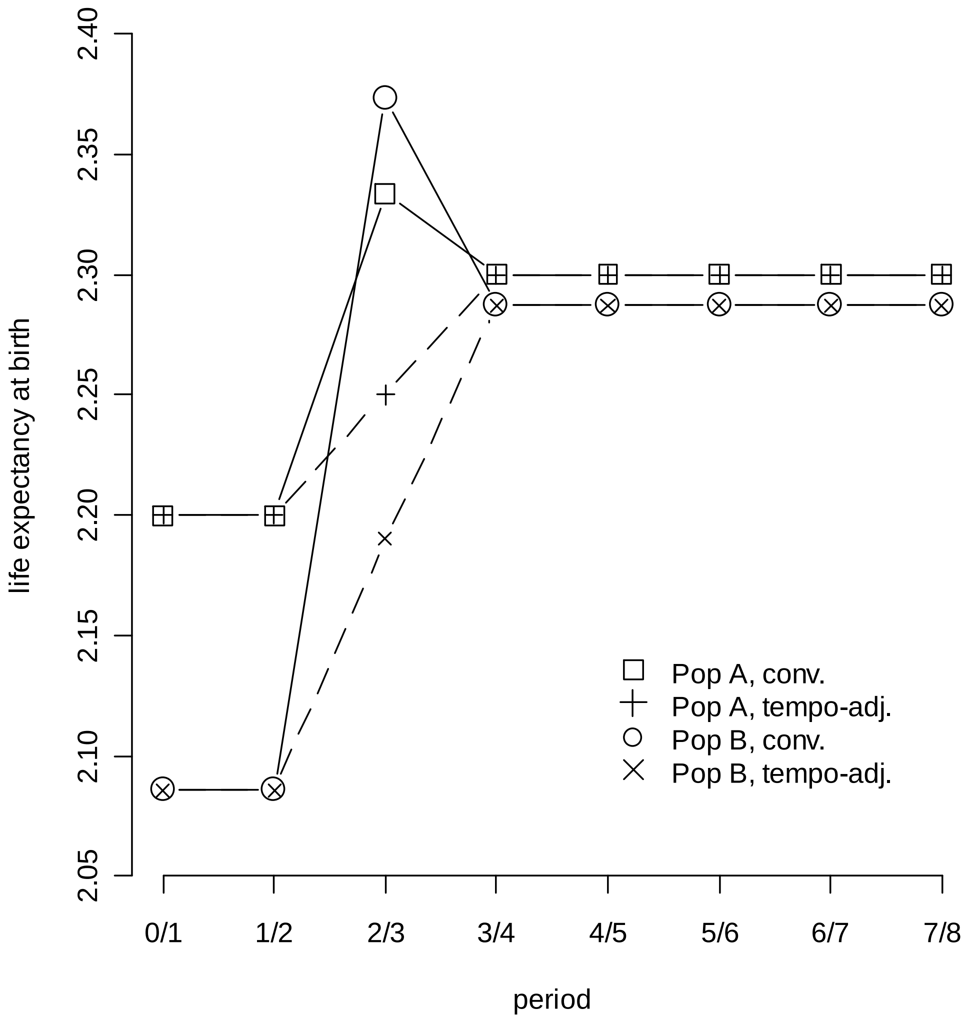


Figure 8: Cohort life expectancies for the cohorts of populations A and B assuming constant q(x) (conventional life table assumption)

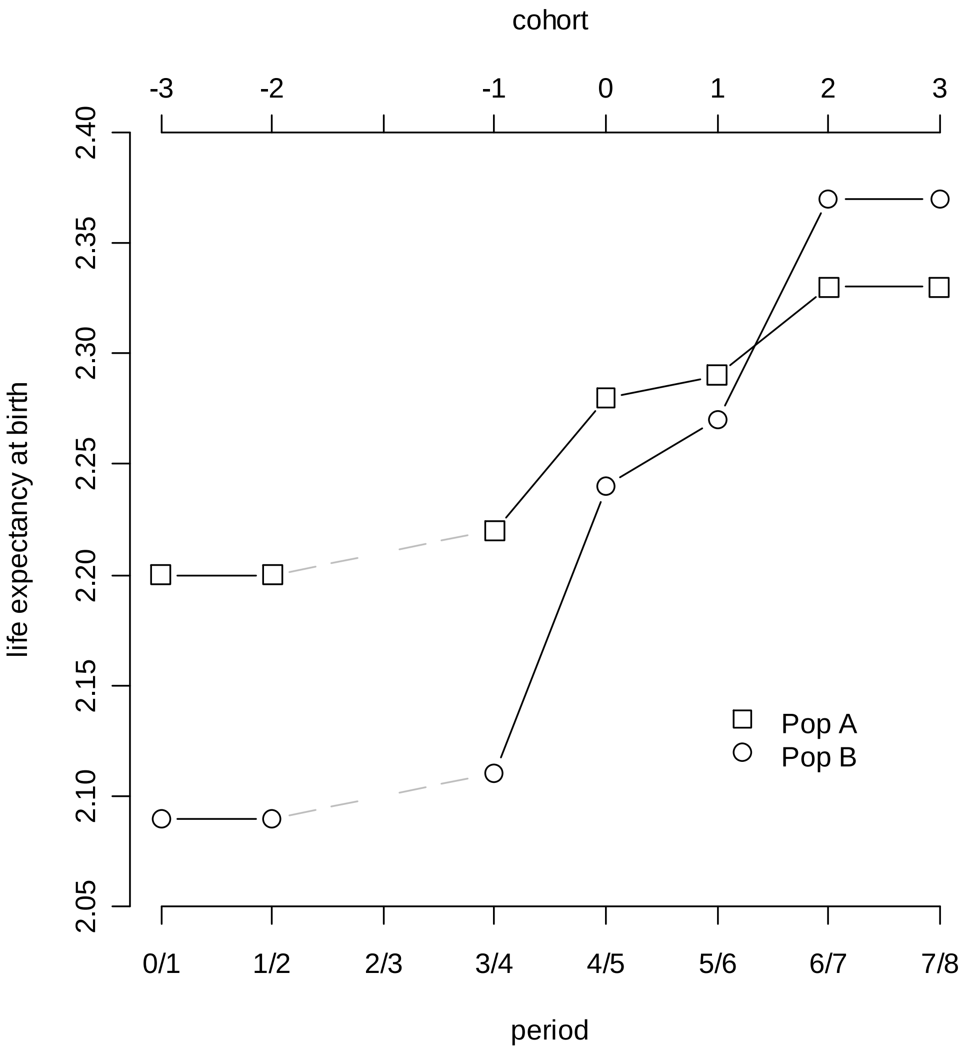


Figure 9: Conventional and tempo-adjusted period life expectancy for population A and population B assuming constant q(x) (conventional life table assumption)

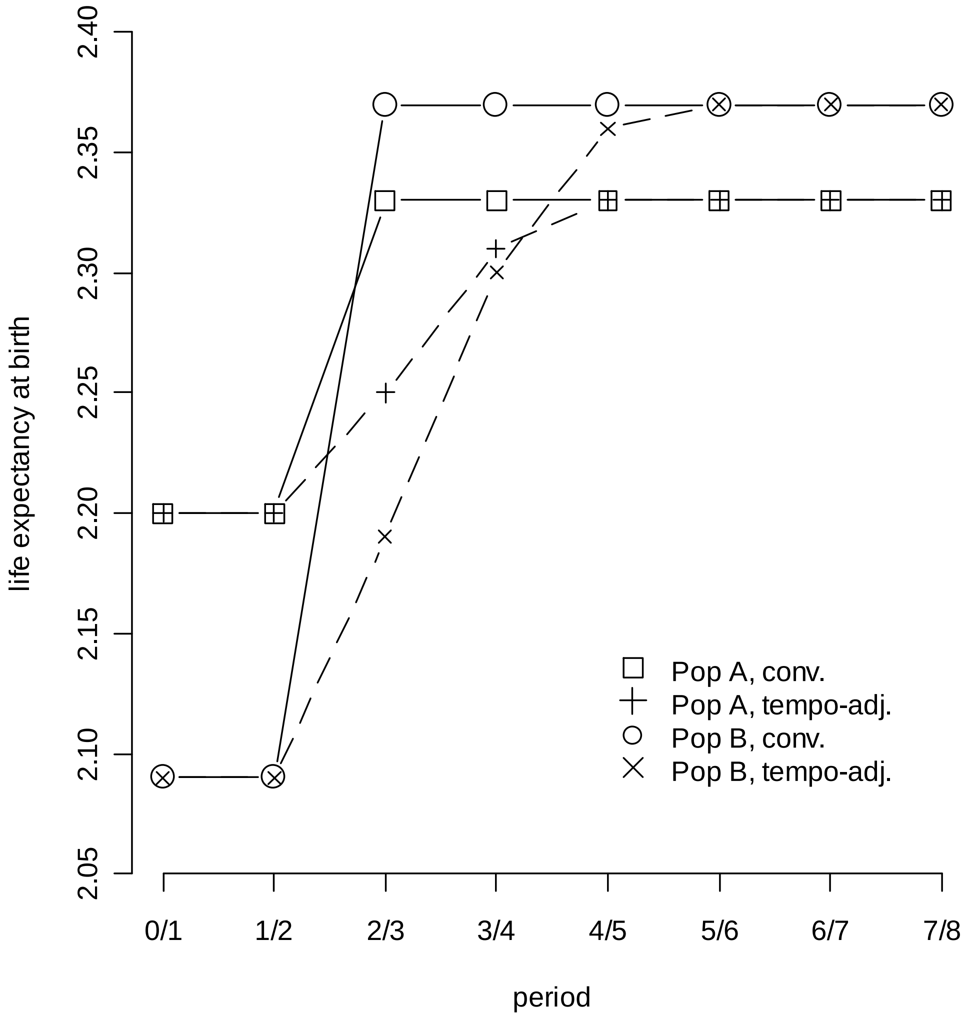


Table 2: Conventional life expectancy e(0) and tempo-adjusted life expectancy e(0) for 41 countries, females 2001-2005, no tempo effects below age 30*

				rank	
	e(0)	e(0)*	difference	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

Table 3: Conventional life expectancy e(0) and tempo-adjusted life expectancy e(0) for 41 countries, males 2001-2005, no tempo effects below age 30*

				rank	
	e(0)	e(0)*	difference	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