# A newly recognized problem in the interpretation of life expectancy

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## Introduction

Period life expectancy (PLE) is one of the most used indicators of population health since it is based on data that are available in almost all countries in the world.(1) It is independent of the age structure of a population and has a clear and intuitive interpretation: the average number of years a newborn would live if current mortality rates would prevail throughout its life.(2) Population health researchers often use life expectancy to make comparisons between countries or over time, and usually interpret life expectancy as an indicator of the prevailing mortality conditions in the respective year.

Recently, doubts on the reliability of PLE as an indicator of current mortality conditions have been formulated, in particular during periods of sudden and large changes in mortality, as for instance during the turmoil caused by the transition to market economies in Eastern Europe during the 1990s or the sudden improvement in living conditions in East Germany after its re-unification with the Western part.(3-6) In these circumstances, the life table might give an overly optimistic or overly pessimistic impression of the change in mortality conditions. This problem has been discussed extensively in the demographic literature under the name of 'mortality tempo effects'.(7-20) These effects are defined as distortions in death rates due to short-term shifts in deaths to either higher or lower ages during rapidly changing mortality conditions.(21) The aim of this paper is to translate the main arguments of this discussion and their implications to a more general audience of population health researchers.

This new problem in the interpretation of life expectancy adds to some other, more widely known problems. Population health researchers are well aware of the fact that PLE is not a prediction of the number of years those born at that time will live, but merely a summary of prevailing age-specific mortality rates.(22) Also, it has been recognized that changes in PLE are also determined by positive or negative selection effects of past developments which could either work in a period or cohort direction.(23)

The structure of this paper is as follows. We first review the discussion on ‘tempo effects‘ in the recent demographic literature, then we provide an illustration based on the convergence of PLE between former West and East Germany after the German unification, and we end with a few general conclusions and suggestions for population health researchers.

## Mortality tempo effects

Life expectancy is defined as the average age to which the members of a birth cohort survive over their life course.(2) Its computation requires about a century of data and therefore usually a shortcut is to use observations of one period only. Here, all age-specific death rates observed at a single point in time are combined to calculate the average length of survival of a hypothetical cohort. The advantage of PLE over other summary measures of mortality is that it standardizes for differences in the age-structure of populations and provides an up-to-date summary of the prevailing mortality conditions.

However, starting in 2002, a series of papers surprised the demographic community, claiming that life tables are distorted whenever mortality is changing, due to so-called mortality tempo effects.(7, 16, 24) These effects belong to a larger class of distortions defined as *"an undesirable inflation or deflation of a period [...] indicator of a life-cycle event"*.(25) The general idea is that any period measure is prone to timing shifts of the events it counts, which in the case of mortality refers to postponements of deaths. Consequently, the change in the indicator does not necessarily represent the actual change in underlying mortality conditions in the population.

The extent of a 'tempo bias' depends on a rarely acknowledged feature of the life table. When mortality is changing, variations in death counts are weighted with the remaining life expectancy at each age. (12, 16, 26) Hence, the change in PLE over time is guided by hypothetical weights rather than the real improvement in survival time in the population. This might be reasonable if the additional survivors are as healthy as the average population, e.g. people saved from dying in a traffic accident.(19)

But this assumption is not reasonable in all situations. A simple example, given by Vaupel, is the case where every death in a population is suddenly postponed by one year.(27) Although this delay by definition increases the average survival time of the population by one year too, the PLE would temporarily increase to infinite, as no deaths are observed in the year in which the change happens. A less drastic case has been described by Bongaarts & Feeney, who show for a model population that a delay of all deaths by 0.3 years during a period translates into an overly optimistic change in PLE of about 3 years instead of the expected 0.3 years.(7)

- Figure 1 about here -

The mechanism underlying mortality tempo effects is schematically shown in figure 1, where a theoretical population is shown in which annually 100 deaths occur to 1000 person-years at risk. Its PLE is 10 years, calculated as one over the mortality rate of 0.1.(2) At time t=2, however, suddenly half of the deaths are saved and shifted to the next period. This 50%

reduction in the mortality rate will increase PLE to 20 years according to the conventional life table calculations, computed as one over 0.05. Implicitly, these calculations assume that the deaths avoided at time t=2 will be gradually distributed over the next time-periods according to the current average remaining life expectancy, which is 20 years. However, the deaths are in fact only postponed by one year. If this shorter delay would properly be accounted for in the life table calculations, life expectancy at time t=2 would only be 10.5 years, since in fact half of the population gains one year. The difference between 20 and 10.5 is the tempo effect, here 9.5 years. Similar distortions will occur in case of a sudden increase in the number of deaths.

The size of a tempo effect depends on the difference between the amount of time the death events were shifted at each age (short-term shift) and the remaining life expectancy at that age (life table assumption). The example given above shows the consequence for the estimation of PLE if deaths were shifted by one year, while the remaining life expectancy at each age is 20 years. In addition to a single shift also a continuous shift might occur.(8) While in the case of a single shift, PLE is only overestimated (or underestimated) in the year the shift occurs, in the case of a continuous shift a permanent inflation (or deflation) occurs.

No matter which of these details applies in a practical case, a general precondition for the existence of tempo effects is a strong increase or decrease in observed PLE related to an underlying short-term shift in the age at death. The latter is by definition a latent construct as the actual shifts are not directly observable. However, if a clear intervention could be identified that might cause a large short-term shift of deaths, the potential existence of tempo-effects should be taken into account. Such an approach will be demonstrated in the next section for the case of the former German Democratic Republic where after reunification in

1990 both preconditions for tempo effects - a clear intervention and a rapid change in mortality – were met.

**An illustrative example**

To illustrate the impact tempo-effects may have on trends in PLE, we make use of the sudden changes observed after the reunification of Germany. The populations of West and East Germany had lived for 40 years in completely different economic and political systems, until both parts were reunited in 1990. Separation and unification coincided with divergence and convergence in PLE of East Germany as compared to its western counterpart in particular pronounced for females (figure 2). Starting from an equal level of about 75 years in 1970, the gap between the two parts of Germany increased to almost three years in 1990 and finally disappeared again after reunification.

- Figure 2 about here -

The case of the rapid East-West German convergence in life expectancy calls for a closer examination.(31, 32) Detailed analyses suggest that general living conditions even deteriorated in East Germany immediately after reunification, due to privatization, mass unemployment and a significant increase in motor vehicle accident mortality.(33) At the same time health-related lifestyles improved only slowly.(34) The only reasonable explanation for a sudden decline in mortality rates is the rapid improvement of medical technology and health care, in particular nursing care.(6, 11, 35, 36)

If this explanation is correct, mainly frail persons have benefited from improved health care right after reunification. Consequently a large fraction of postponed deaths might have been delayed by a short period only, and tempo-effects are likely to have occurred. We have simulated the impact of such tempo effects on life expectancy in figure 3 using data from the Human Mortality Database.(37) (see online supplement for data and methods). Our scenario contrasts the conventional PLE in West and East Germany with an alternative one based on the assumption of short-term postponements of deaths. For the latter we assumed that the fraction of avoided deaths postponed by a short time only was large immediately after reunification, and gradually diminished in later years. As visible in figure 4, after reunification in 1990-94 the rate of improvement of life expectancy in the Eastern part of Germany is much lower in this alternative scenario than suggested by conventional calculations of life expectancy, while it is higher than suggested by conventional calculations in the later years 2000-09.

In other words, if tempo effects have distorted changes in life expectancy, the pace of improvement in underlying mortality conditions was over- and then underestimated. Solely based on aggregate mortality data, the actual extent of these de- and inflation processes is hard to quantify. However, this example demonstrates that looking at PLE only may leads to a misleading interpretation.

- Figure 3 about here -

- Figure 4 about here -

## Discussion and conclusion

The present paper introduces a problem so far not acknowledged in public health, but extensively discussed in aging and mortality research in the recent decade. Those who apply life tables should be aware of the assumption it uses to assign remaining life-years to avoided deaths. If during times of rapid progress a large fraction of deaths is merely delayed by a few months or years, an overestimation of the real improvement in underlying mortality conditions is likely to take place. Similarly, if during times of a rapid increase in death rates a large fraction of deaths is merely brought forward by a couple of months or years, an overestimation of the real deterioration in underlying mortality conditions is likely to occur. If the change in life expectancy is used as an indicator for the improvement of underlying survival conditions of the population prevailing at that time, errors of interpretation may occur.

Although tempo effects in mortality rates have widely been discussed in the demographic literature, the concept has rarely been applied so far, which is due to the absence of a consensus on an appropriate adjustment tool.(38) The key element thereby is the estimation of the rate of change in mortality conditions, which is responsible for shifting deaths to either higher or lower ages. Current techniques to estimate this change in mortality conditions first reconstruct the full history of the currently living cohorts, taking into account mortality rates of the past, and then quantify the change in the average survival of these cohorts from one year to the next.(24, 38) However, these techniques have been criticized because they do not provide falsifiable predictions.(10, 18, 39) This fundamental problem could be tackled by identifying the presence or absence of a large fraction of short-term shifts in death events between two periods for a population, in particular related to the presence of persons with a high mortality risk. For this purpose detecting changes in the health status of the population could be useful. If indeed short-term shifts let a large fraction of the people that are about to die survive a bit longer, one could expect to observe a detectable accumulation of frail persons in the subsequent years. However, observed increases of frailer persons can also originate from an increase in the incidence of diseases instead of improving survival.

To conclude further research should focus on the empirical identification of short-term delays of deaths, and combine statistical models and various empirical data sources to test for the existence of tempo effects and their impact on the change of PLE.

As suggested by the example of East Germany, health care as an important determinant of life expectancy is one of the main candidates being able to immediately lengthen the life of people that are about to die by a few months or years.(11, 21, 40) A recent example of such a health-care related influence is the case of the Netherlands, where an expansion of health care for the elderly and more frequent use of life-prolonging interventions, facilitated by relaxation of budgetary constraints of hospital expenditures, coincided with a sharp increase in PLE.(41)

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## Contributors

FP and WJN developed the concept of the study, while JPM translated the topic into the field of public health. FP drafted the manuscript and developed and calculated the model used in the illustrative example. JPM and WJN critically reviewed the different versions of the manuscript. All the authors have read and approved the final version to be published.

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