How long do we live? Demographic models and reflections on tempo effects: An introduction

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1 Background

The measurement of human longevity is one of the oldest topics in demography. The most widely used measure of longevity is the period life expectancy at birth which is calculated from age specific death rates by life table methods that originated with Graunt (1661) and have been standard in the field for well over a century. Period life expectancy equals the mean age at death in a synthetic cohort and it should be distinguished from the actual cohort life expectancies calculated for a group of individuals observed over long time periods.

A *tempo effect* is defined as an inflation or deflation of the period incidence of a demographic event (e.g., births, marriages, deaths) resulting from a rise or fall in the mean age at which the event occurs (Bongaarts and Feeney, in this volume p.11 and p.29). The existence of tempo effects has been well established in measures of fertility and nuptiality but the idea that mortality measures may be also affected is new and controversial.

Tempo effects were first discovered and analyzed in the study of fertility. If women shift the ages at which they bear children upward without changing their completed fertility, annual numbers of births will be less than they would have been because the same number of births will be spread out over a longer time period. Similarly, if women begin to have children at younger ages, annual numbers of births will be larger than they would have been because the same number of births occurs over a shorter time period. These changes in annual number of births induced by changes in the timing of childbearing are tempo effects. The post-war "baby boom" in the United States, for example, was due in part to a decline in the mean age at childbearing during the late 1940s and the 1950s (Ryder, 1964,1980) and in much of Europe recent period fertility levels are depressed by tempo effects resulting from the postponement of childbearing (Sobotka, 2004). Tempo effects complicate the study of

levels and trends of fertility because they produce changes in period fertility rates that depend on the rate at which the mean age at childbearing changes, independently of changes in completed fertility of cohorts. Ryder (1956) introduced the term "timing distortion" to refer to tempo effects in the total fertility rate because they are undesirable in most analyses of fertility levels and trends.

Ryder's pioneering work established the existence of tempo distortions in the total fertility rate, but he did not propose quantitative adjustments to remove tempo distortions. This may be explained in part by his strong emphasis on the conceptual priority of cohort fertility measures. Bongaarts and Feeney (1998) first proposed to remove tempo distortion from the period total fertility rate. Their tempo adjustment is obtained by dividing the observed total fertility rate by $1 - r$, where r equals the annual change in the period mean age at birth. Recent applications of this method to obtain tempo adjusted fertility levels by birth order in many European countries are presented in Sobotka (2003, 2004). The same method can be used to remove tempo distortions in period nuptiality measures as demonstrated by Winkler-Dworak and Engelhardt (2004).

Bongaarts and Feeney (2002, in this volume p.11 and p.29) noted that tempo effects affect the numerators of all period event rates. As a result, tempo effects inflate and deflate not only incidence rates such as conventional age specific birth or marriage rates (rates of the second kind) but also occurrence/exposure rates (rates of the first kind). Kohler and Ortega (2002,a,b) propose procedures for calculating period fertility measures based on tempo adjusted occurrence/exposure rates and applications of this method are found in Sobotka (2003) and Winkler-Dworak and Engelhardt (2004).

The possibility that period life expectancy contains tempo effects was proposed and studied by Bongaarts and Feeney (2002, in this volume p.11 and p.29). They reasoned that if occurrence/exposure rates for births and marriages contain tempo effects then the same should be true for occurrence/exposure rates of other events such as deaths. Period life-expectancy derived from these rates therefore should contain tempo effects as well when the mean age at death changes. Their studies also propose an adjustment to remove the tempo effect which is conceptually similar to the adjustments made in fertility and nuptiality measures.

Tempo adjusted period measures of fertility, nuptiality and mortality should be interpreted as variants of their conventional counterparts. The life expectancy at birth, for example, is defined as the average age at death of a newborn subjected throughout life to the age-specific death rates observed in a given year. This is a hypothetical lifespan because no actual cohort will experience these observed period death rates. According to Bongaarts and Feeney, the tempo adjusted life expectancy is a similar hypothetical measure, but one that corrects for distortions caused by year to year tempo changes. Neither the observed nor adjusted life expectancy attempts to estimate the mean age at death of any actual cohort, nor do they attempt any prediction

of future mortality. The goal of the tempo adjustment is simply to provide period quantum and tempo measures that are free of the tempo distortions.

This volume examines the question whether period life expectancy as calculated by a conventional life table is affected by tempo effects. The interest in the mortality tempo effect has grown recently and has generated an animate debate among scientists involved in mortality research. Some scholars remain unpersuaded about the existence of the effect in mortality but some skeptics have begun to revise their views about the significance of the effect.

In order to promote further research on this important but controversial issue, the Max Planck Institute for Demographic Research (Rostock, Germany), in collaboration with the Population Council (New York, USA), organized an international workshop on 18-19 November 2004 in New York.

The workshop produced a number of high-quality papers. Many of these papers were then revised and submitted for publication to the journal *Demographic Research* and underwent the usual process of peer review. The present volume collects a selection of these articles which have been already published in *Demographic Research* during 2005 and 2006. Furthermore, the volume includes other important studies on the mortality tempo effect which were not presented at the workshop in New York.

2 Overview of the monograph

This collection includes fourteen chapters grouped into four sections, plus an Appendix. Two chapters by John Bongaarts and Griffith Feeney in the first group present the background and the theoretical framework for the mortality tempo effect. The first one, a pioneering work in the field, was published in the *Proceedings of the National Academy of Sciences* in 2003. It shows that observed death rates and period life expectancy as conventionally estimated are distorted whenever mortality is changing and lead to a misleading indication of current mortality conditions. The authors propose an alternative period measure of longevity adjusted for tempo changes. The new measure is based on the assumption that the observed force of mortality at a given time t is proportional to an age intensity defined as the rate at which the proportion of cohort survivors in a population at time t varies from one age to the next. It is shown that this assumption implies uniform delays of death to older (younger) ages as mortality declines (increases). The authors demonstrate that the so-called proportionality assumption is realistic in populations with high life expectancy and when ignoring child and young adult mortality. In the second chapter, published in the *Vienna Yearbook of Population Research* in 2006, the authors extend their previous studies and demonstrate the existence of tempo distortions in period quantum and tempo measures of a wide range of life cycle events. This chapter makes the connection between the fertility and mortality tempo effects and gives a more general framework

for the analysis of the tempo effect in demographic events, with empirical examples for fertility, marriage and mortality.

The second section of the volume, consisting of eight chapters, is devoted to critiques, extensions and applications of the mortality tempo effect. The leitmotif of the first four chapters is the definition and the interpretation of longevity measures for a better understanding of the complexity of mortality dynamics.

German Rodriguez analytically reviews the concept of tempo effect in demography. He analyzes the cohort implications of the Bongaarts-Feeney delay-death model and shows that this is closely linked to accelerated failure time models used in survival analysis. The author emphasizes important similarities as well as fundamental differences between the analysis of fertility and mortality. He argues that in the case of fertility, the adjustments help to distinguish changes in the quantum or tempo. This is not the case for mortality which is a pure tempo phenomenon. When cohorts start delaying death, observed mortality rates decline. Conventional life expectancy reacts instantly, whereas the Bongaarts-Feeney tempo adjusted life expectancy reacts more slowly. According to the author, there is no bias or distortion in the observed force of mortality. The two indicators - the conventional and the tempo-adjusted life expectancy - simply measure different things. Conventional life expectancy depends only on the force of mortality, whereas, the adjusted measure is affected by the age composition of cohort survivors and, thus, reflects past rather than current mortality. So, the conventional life expectancy tells us how long today's newborns will live under the current rates, whereas the tempo-adjusted life expectancy tells us how long those dying today have lived under the proportionality assumption.

James Vaupel argues that life expectancy under current rates and life expectancy under current conditions are different under a broad variety of circumstances. In particular, when mortality is changing, calculations of period life expectancy do not, except in special circumstances, measure the life expectancy of a cohort of newborns that hypothetically live all their lives under the current mortality regime, as argued by Bongaarts and Feeney. The Bongaarts-Feeney delay-death model as well as various models accounting for population heterogeneity in individual frailty are considered special cases. The author then presents a model of stretched lifetimes based on the idea that deaths that would have occurred over some period of time occur over a longer period of time after a mortality improvement. Neither the conventional life table approach nor the delay-death model nor the stretched lifetimes model account for population heterogeneity. Vaupel concludes that the tempo-quantum metaphor may not be optimal and considers the issue of selective survival a better starting point as mortality changes may affect individuals differently. Instead of the narrower term "tempo distortion in mortality" he suggests to use a broader "theory of mortality turbulence" to allude to the general phenomenon that when mortality is changing conventional lifetables do not describe the cohort mortality experience under current conditions.

In the following chapter, Kenneth Wachter focuses on the understanding of what the mortality tempo adjusted measures do measure. He shows that, under the proportionality assumption, the Bongaarts-Feeney measure is an exponentially weighted moving average of period life expectancies from recent past. This dependence on the past is the fundamental property of the mortality adjusted measure. In contrast, the conventional life expectancy is an indicator of current observed mortality. The fact that it is sensitive to sudden mortality changes is, according to Wachter, an advantage, not a drawback. The author concludes that adjustments for tempo do not make obvious sense in mortality but only when there is a distinction between quantum and tempo in individual experience as in the case of fertility.

The existence of tempo effect in mortality is critically examined by Michel Guillot. He concludes that the Bongaarts-Feeney indicator can indeed be considered a period measure under specific assumptions. But he argues that the proportionality assumption is met only if one disregards mortality under age 30 and that this additional assumption may not be appropriate even in contemporary populations. Furthermore, the author asserts that Bongaarts and Feeney's index relies on a particular definition of changes in period mortality conditions which implies, as a result of mortality changes, delays in future cohort deaths that are cohort-constant. Thus, for instance, the fact that the amount of benefits (delays in age at death) of a medical innovation depends on how long before the innovation appeared is not considered in Bongaarts and Feeney's approach. Guillot concludes that until our knowledge of mortality dynamics is better developed, it is preferable to use the conventional life expectancy as an indicator of current mortality conditions.

One of the assumptions in the Bongaarts-Feeney's approach is that delays of death are age-independent. This issue is addressed in the following chapter by Griffith Feeney who introduces the idea of "increments to life" as a complementary perspective to the force of mortality in the study of changing mortality and length of life. The author develops a general mathematical representation of life gains allowing for continuous variation in age and time which provide a method for assessing the robustness of the Bongaarts-Feeney mortality tempo adjustment formula. Furthermore, the formulation of age-variable increments to life is useful to avoid a restrictive assumption of the Bongaarts-Feeney approach, that is the assumption of ignoring mortality changes in infancy, childhood and young adult ages. Linked to this chapter is an appendix by Jutta Gampe and Anatoli Yashin who provide two different proofs for the first formula appearing in Feeney's chapter. This formula, for which the author did not give a mathematical proof, decomposes the difference between the expectations of life at birth for two cohorts in terms of the increments to life values.

An alternative way of dealing with mortality tempo is devised by Hervé Le Bras. The author proposes a model where mortality changes take place with the removal of a given cause of death. This may produce a delay in death but, contrary to Bongaarts-Feeney delay-death model, one that de-

pends strongly on age. In the removal model, there is no discrepancy between cross-sectional and longitudinal indexes, period measures of longevity are not distorted and, thus, no correction is needed. The author claims that the proposed method is more general and better suited to the true nature of mortality processes. He concludes that the removal method should be preferred to the delay method.

The following two chapters support enthusiastically the idea of tempo effect in mortality. Shiro Horiuchi investigates the effects of changes in the age distribution of cohort deaths on the age-specific number of period deaths and, in turn, on the age-specific period death rate, under the assumption that the age-specific number of deaths is constant among cohorts but allowing for non parallel shifts in the age distribution. He first gives an intuitive and visually oriented demonstration that a tempo distortion can in effect occur in age-specific mortality. Then he provides a mathematical representation of the mechanism. However, Horiuchi recognises that the study presented clarifies the logical mechanism of only one of all possible pathways through which mortality changes can affect period measures.

Finally, Marc Luy also has no doubt about the existence of tempo effects in period life expectancy and the distortions they may cause (this chapter does not spring from the workshop in New York). A shorter version of this chapter was recently published in *Demographic Research*. Here we reproduce an extended version including an extension of an example provided by Feeney (2003) in his unpublished paper "Mortality tempo: a guide for the skeptic". Luy presents an application of the Bongaarts-Feeney method to the analysis of mortality differences between western and eastern Germany. The results from tempo-adjusted life expectancy provide a better fit than those from the conventional life expectancy to the expected trends of changing mortality in Germany. As a consequence, the author claims that the adjusted life expectancy is a more realistic indicator of the level and changes in current mortality conditions than the conventional life expectancy. Luy concludes that, although the Bongaarts-Feeney adjusted measure can be improved since it is based on strong assumptions, their approach should be preferred as long as there are no better solutions.

The third part of the volume includes two chapters focusing on the comparison of period and cohort measures of longevity. John Bongaarts summarizes five recently proposed period measures of longevity and shows that three of the five measures are identical to one another under the assumption that mortality follows a Gompertz model with a constant rate of improvement over time. These measures, however, differ substantially from the conventional period life expectancy when mortality changes over time. The author notes that these empirical findings are consistent with the theoretical analysis by Bongaarts and Feeney which showed that the deviation of conventional life expectancy from the other longevity measures is caused by a tempo effect whose size varies with the rate of change in mortality.

The following chapter by Joshua Goldstein shows that, under the Bongaarts - Feeney's assumption of uniform postponement of death across all ages, the additional assumption of linear mortality shift, and ignoring mortality below age 30, the tempo-adjusted life expectancy for a given year t, $e_0^*(t)$, is equal to the life expectancy of the cohort dying in that year t, that is the cohort born $e_0^*(t)$ years earlier. Accordingly, Bongaarts-Feeney period longevity measure corrected for tempo distortion may be seen also as a measure of cohort life expectancy. The author concludes that, in case of sudden mortality change, the tempo adjustment is useful for understanding the implications of mortality rates during shocks. However, in recent years, almost all the developed countries have experienced a steady mortality decline, a situation in which the cohort interpretation gives more valuable sense.

Two chapters in the final section of the volume summarize the discussion about the existence and the meaning of the mortality tempo effect. In their concluding note Bongaarts and Feeney comment briefly on the main question that has been raised by some chapters in the volume about their analysis of the tempo effect and their proposal to remove this effect by adjusting the conventionally calculated life expectancy. This question is whether the tempo adjusted life expectancy is a current measure of mortality conditions as they and Vaupel and Guillot believe, or a measure of the past mortality as suggested by Rodriguez and Wachter. The authors also discuss the assumptions underlying their tempo adjustment and argue that these assumptions hold for senescent mortality which dominates in contemporary low mortality countries.

The issue of distortion in period death rates and life expectancy occurring whenever mortality is changing is complicated and difficult to explain. For this reason, James Vaupel presents four simple examples which clearly show how lifesaving can roil lifetable statistics. He concludes that the question about the existence of tempo effects in mortality is open but there is no doubt that mortality change produces turbulence in lifetables. However, how much life is extended when a death is averted is a question that needs further research.

What is then the "true life expectancy"? There is no doubt that the conventional period life expectancy is not an accurate measure of longevity of people born in or living in a given year. However, the debate on how best to measure period longevity, the existence of tempo distortion in mortality and the need of adjustments in longevity measures is still open. Nevertheless, I believe that this set of insightful studies makes an important step toward a deeper understanding of the population dynamics and the tune of valuable longevity measures, and hope that it will stimulate further extensive research in the field.

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