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**Detecting the 'Big Red Spot' of Age-Period Excess Mortality in 25 countries:
Age-Period-Cohort Residual Analysis**

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Short abstract

In times of wide availability of yearly mortality information of age and period groups all over the world, we lack in tools that detect and graph fine-grained deviations from mortality trends. We provide a new age-period-cohort based methodology, combining information from age-period (AP) and APC-Detrended (APCD) analyses to detect all-cause mortality increases. Plotting the resulting AP coefficients and APCD residuals in equilateral Lexis diagrams, mortality patterns can easily be distinguished as age, period, or cohort trends and fluctuations. Additionally, we detect abnormalities as interactions of age and period ('big red spots'). We then investigate the 'red spots' of mortality of young-adult cohorts in the early 1990s in Spain, other southern European countries and the U.S. to delineate their simultaneously occurring public health crises. Additional analyses with WHO mortality data show that mortality increases are mostly due to increased HIV/AIDS mortality. We discuss possible applications of the new method.

Introduction

In times of wide availability of yearly mortality information of cohorts all over the world all across their life span, there is still no tool available that easily detects and intuitively graphs fine-grained deviations from the overall mortality trends. The Global Burden of Disease Study has undertaken large efforts to collect high-quality mortality information by country, age, gender, and cause of death, and life expectancy tables provide helpful guidance on where public health response is adequate and where it could be improved (Lozano et al., 2013). Nonetheless, those analyses do not consider trends in mortality per period and cohort, much less deviations from overall trends which could point to localized health crises. Indeed, research has struggled to

date to properly distinguish period from cohort mortality trends, and research efforts that have been successfully ruling out period effects in mortality without APC methodology usually need a reference population to quantify cohort effects (Lindahl-Jacobsen et al., 2016). Our method overcomes these limitations since we focus here on residuals and not on predictions of APC. We propose to use a new combination of AP and APCD methodology (Chauvel & Schröder, 2014, 2015) to plot mortality by year and age per country.

The paper is structured into two parts: In the first part, we introduce the new method and plot male mortality for selected countries based on data from the Human Mortality Database (HMD, downloaded from www.mortality.org on July 7, 2016). This multi-country fine-grained database with yearly mortality information (by birth year and calendar year) offers unique opportunities for detailed description. We detect abnormalities in the sense of localized mortality increases ('big red spots') of young-adult cohorts in the early 1990s in several countries. In the second part of the paper, we analyze those mortality deviations in more detail. More specifically, additional analyses are guided by the hypothesis that mortality increases during that time may be attributable to HIV/AIDS mortality. We confirm this assumption with data from the WHO Mortality Database.

Part I: Introducing the New Method

Our method consists of three steps:

First, we analyze mortality patterns across age (25-60) and calendar years (1975-2010) by plotting one-year *age-period* (AP) *mortality* (derived from Human Mortality Database) for 25 countries in an equilateral Lexis diagram (see Tafel 1, Figure 2 in the Appendix of Lexis, 1875; Keiding, 1997, 2011; Riffe, 2011). The equilateral Lexis is widely known among epidemiologists and demographers and helps with an intuitive representation of mortality trends being a cohort (down-left to upper-right diagonal) or period effect (down-right to upper-left diagonal) or an interaction of both. Figure 1 and Annex Figures 1 and 2 give an overview of information contained in this diagram and how mortality patterns can be interpreted.

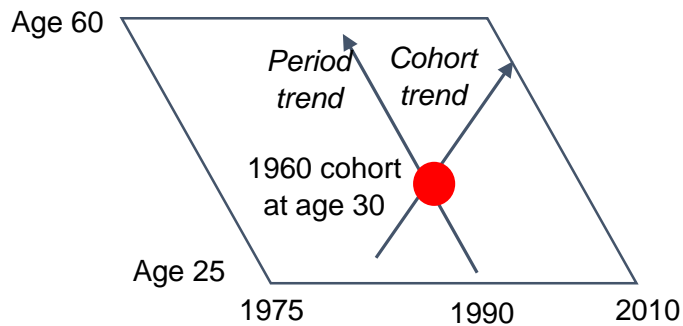


Figure 1. A theoretical equilateral Lexis diagram containing AP mortality coefficients by age and period, illustrating a 'red spot' which would indicate here localized 10 % elevated mortality patterns of 1970-born individuals in 2000.

We use the `spgrid` and `spmap` Stata ado files (Pisati, 2004) to draw these equilateral Lexis. We graph the resulting (A, P) residuals to detect 'red spots' of excess mortality, an abnormality expressed as a specific period-cohort interaction that points to localized increases from expected mortality patterns for one or more birth cohorts in one or more calendar years (a red-colored coefficient equals at least a 10 % increase compared to the expected mortality pattern). The 'blue spots', which points to localized decreases in expected mortality patterns of around 5 %, is less relevant for this analysis of public health crises¹.

¹ Note that in this cross-country comparison we depart from different mortality levels, i.e. low early-age mortality in many European countries in the 1980s and 1990s, but rather high early-age mortality at that time in the U.S., driven by extremely high homicide rates of young adults related to the crack cocaine epidemic (Dahlberg, 1998). In the full paper we will provide descriptive statistics and an in-depth analysis of the relation between 'background' mortality and the intensity of the 'big red spot'.

Second, we use residuals of *APC-Detrended (APCD) mortality analyses* (APCD was presented first on income (Chauvel & Schröder, 2014); and then in different contexts of ecological behavior, political participation or suicide (Chancel, 2014; Chauvel, Leist, & Ponomarenko, 2016; Chauvel & Schröder, 2015). The APCD model acknowledges that linear trends in APC models cannot be robustly attributable to age, period or cohort (Mason & Smith, 1985): it is impossible to know whether linear change stems from a cohort, or from an age plus period effect. Therefore, the model focuses on fluctuations (non-linearity) of the effects of age, period and cohort around a linear trend. Thus, the model absorbs linear trends by appropriate coefficients to focus on accelerations and decelerations in age, period and cohort trends:

$$y^{apc} = \alpha_a + \pi_p + \gamma_c + \alpha_0 \text{rescale}(a) + \gamma_0 \text{rescale}(c) + \beta_0 + \left(\sum_j \beta_j x_j \right) + \varepsilon \text{ (APCD)}$$

where $\alpha_a, \pi_p, \gamma_c$ are sum zero and trend zero; α_0 and γ_0 absorb age and cohort trend

The conventional way of using APC models is to express coefficients (at first, for birth cohorts) to contrast lucky and unlucky cohorts. This means the residuals of the (A, P) models, without cohort, are expected to present upward right lines following cohort (Fig. 2).

A less usual way in APCD is to focus on the APCD residuals since they are often considered as unstructured noise. On the contrary, these residuals can be strategic information that equilateral lexis will expose (Fig 3a) with a focus on the +/- 10 years around the point age 32 in period 1992 (Fig 3b).

Those residuals indicate mortality variance that cannot be explained by detrended age, period, and cohort coefficients, are plotted into an equilateral Lexis diagram, thereby using information on the center of the 'red spots' of the AP mortality analysis. We focus this analysis on the 'red spots' only (a full diagram would contain the same but also much irrelevant information), by plotting only 10 birth and calendar years around the red spot; think of a magnifying lens only focusing on the area of interest. This graphic illustration of APCD residuals gives an impression of the magnitude of the age-period interaction (with red color indicating again highest magnitude). Lastly, and in order to complement the identification of mortality crises, we rerun AP mortality analyses by suppressing the 'red spot': we use the coefficients of APCD analysis (Figure 3b) as a *covariate* of the (A,P) model, i.e. the values of the residuals inside the 10 years

circle around point age 32 in period 1992, and zero elsewhere. This enables us to detect if the mortality crisis of a birth cohort came 'with a warning', i.e. if it results from a long-term disadvantage of birth cohorts, or if the mortality crisis appeared abruptly. At the same time, *plotting* the 'red spot' enables us to detect localized mortality crises resulting from period-cohort interactions, whereas *suppressing* the 'red spot' enables us to even better detect cohort effects in APCD analysis (Figure 4).

We use data from the Human Mortality Database and choose age groups 25 to 60 in the years 1975 to 2010 (i.e. cohorts born between 1915 and 1985) as our window of observation for 12 countries. Some countries are selected for their intrinsic interest to be considered in this topic (localized public health crises are known for Spain, the U.S. and some southern European countries). For some countries, data for the full time range under investigation are not available (Israel, Greece). We also do not report results for countries without any substantial mortality deviations, e.g. Belgium.

Results

In a first step, AP coefficients are used to illustrate mortality patterns for 25 countries (Figure 2). Again, diagonals from lower-left to upper-right delineate cohort effects, diagonals from lower-right to upper-left delineate period effects. See for example the Danish cohort of 1950 with elevated mortality patterns across the window of observation. Focusing on 'red spots', i.e. age-period interactions indicated localized health crises, only, we detect notable mortality increases for young-adult cohorts (more specifically, the birth cohort of 1960 and those adjacent) in the early 1990s in Spain, the U.S., France, Portugal, Switzerland, Canada, Netherlands, and Denmark.

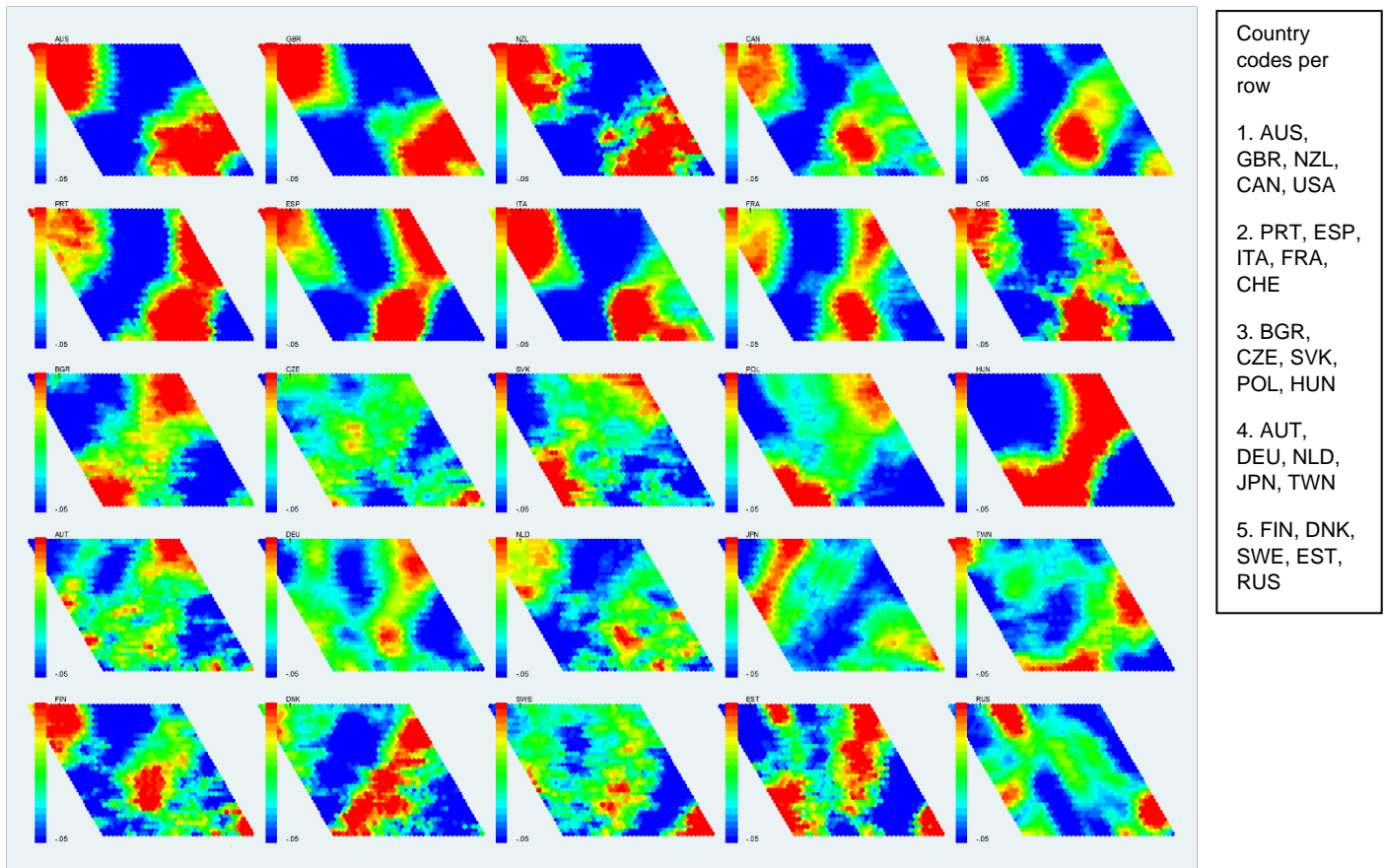


Figure 2. Residuals of (A,P) model, excess mortality in red.

Note: Mortality with strong birth cohort component appear when clear upward-right diagonals are figured (Hungary, Denmark, Japan). Period-related mortality trends are characterized by left-upward diagonals (Spain, Russia).

In a second step, in order to assess the magnitude of the detected age-period interaction, we run an APCD analysis and plot the resulting residuals again in an equilateral Lexis diagram (Figure 3a). In order to omit irrelevant information, we only select a 10-year interval around this spot (i.e. cohorts of 1951 to 1971 and calendar years 1983 to 2003) for a magnifying lens illustration. Figure 3a illustrates that the magnitude of the detected public health crisis varied considerably across countries, with Spain, France, Portugal and Switzerland having a larger increase in mortality of cohort 1960 in calendar year 1992 than the U.S., Canada, the Netherlands, and Denmark.

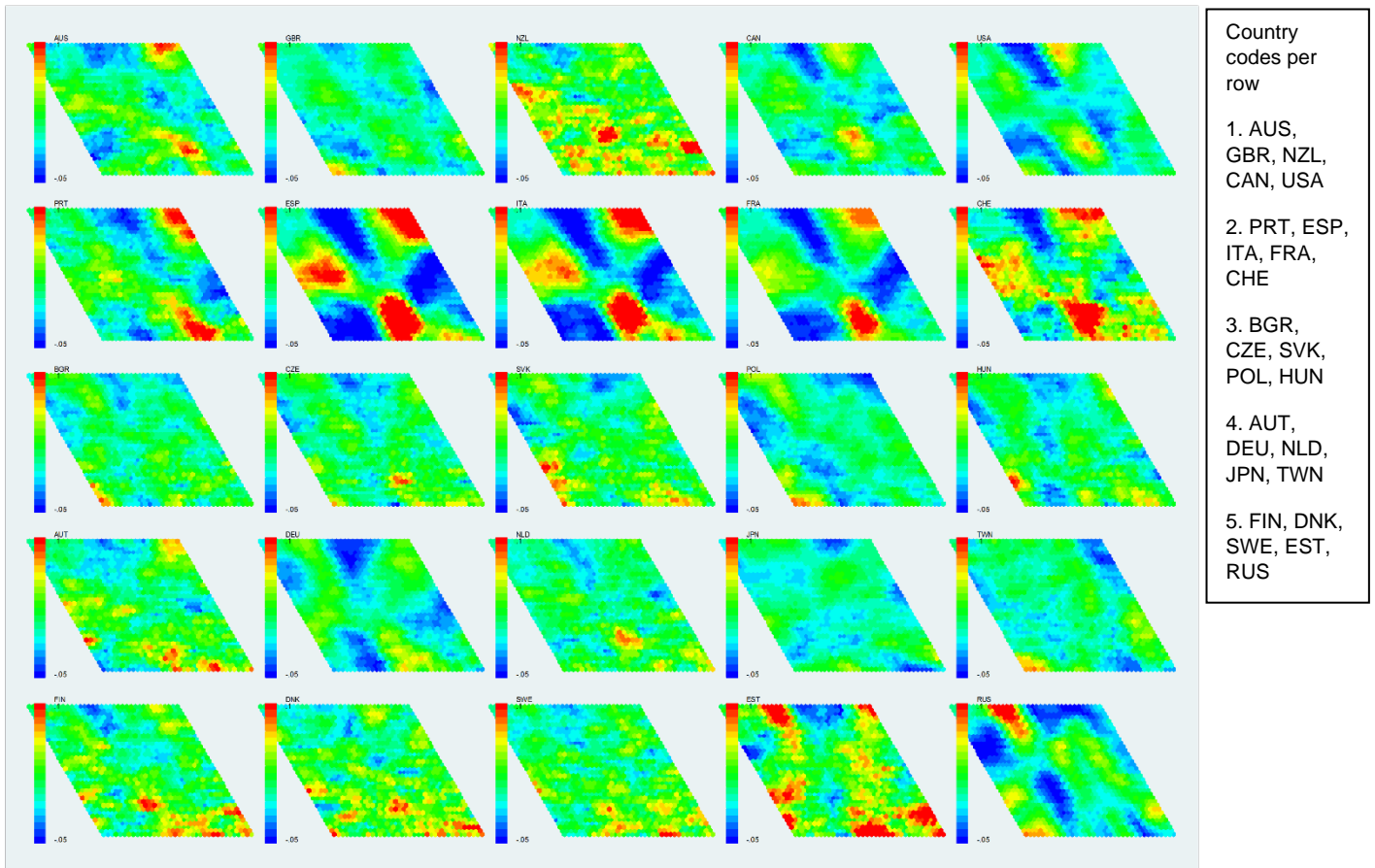


Figure 3a. Residuals of APCD model, excess mortality in red.

Note: APCD residuals help detect abnormalities. Apart from the strong Russian/Estonian end of 1980s seniors excess mortality, the European Latin countries (Spain, Italy, France, etc.) show a 'big red spot' of the 30+-year-olds in the early 1990s as an unexpected singularity.

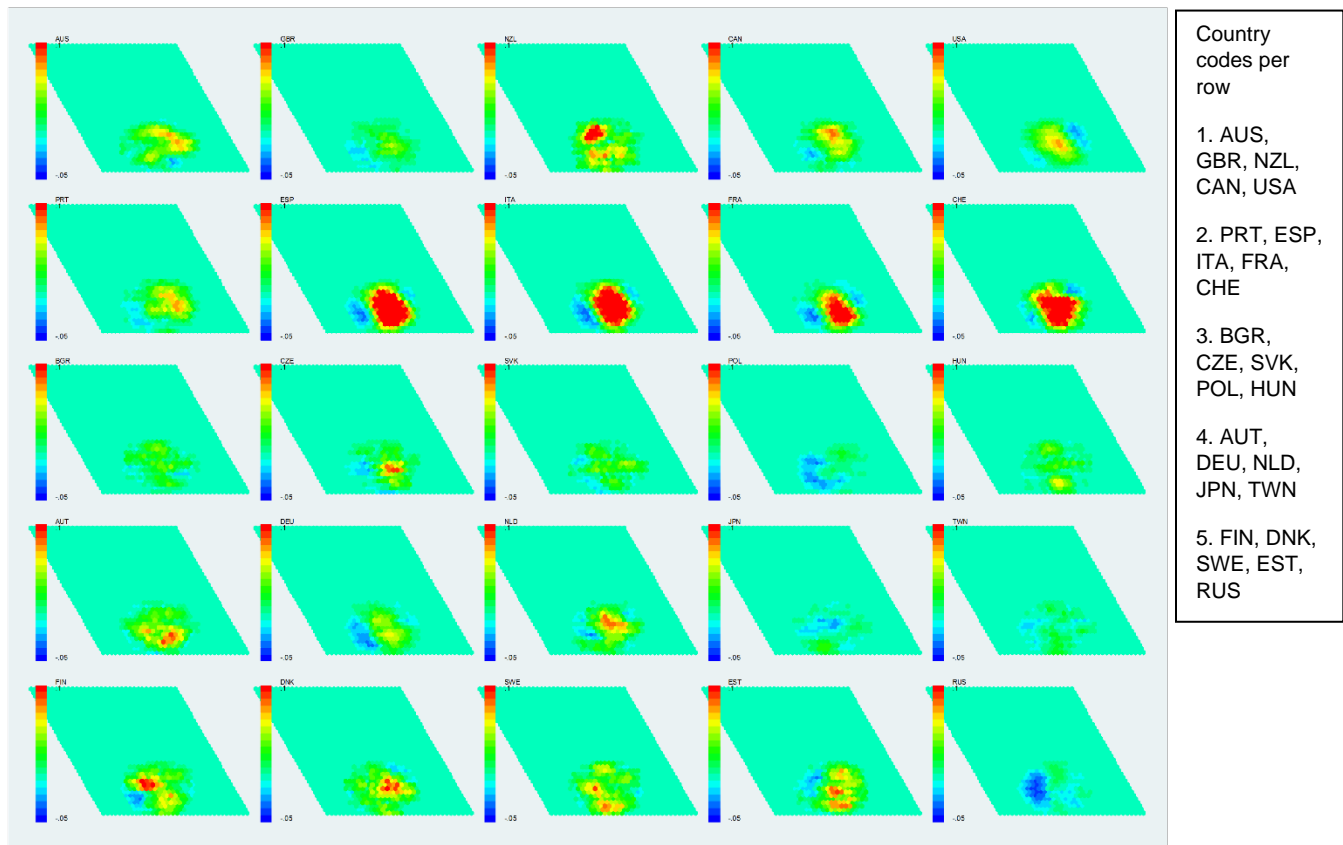


Figure 3b. Residuals of APCD model, excess mortality in red / focus on the big red spot (age 32 in period 1992, i.e. cohort of 1960).

Note: APCD residuals are displayed only for the 10-year circle around cohort 1960 at age 32. Strongest examples are Spain and above mentioned countries, and several further countries such as the U.S. and Canada shows the same singularity, whereas others do not show excess mortality for that cohort and time at all.

In a last step, we are curious to which extent the 'red spots' are localized in the context of a longer-term cohort effect of unlucky cohorts being hit hardest by public health crisis. In order to arrive at the *net* cohort effects, we rerun the APCD analysis after suppressing the 'red spot', i.e. age-period interaction. Doing this, we do not only improve the quality of the APCD analysis as a cohort bump detector (Chauvel, Leist, & Ponomarenko, 2016), but also gain information on the extent to which possible cohort effects exist. We plot the resulting APCD residuals in an equilateral Lexis diagram (Figure 3b). Most cohorts in those countries affected by a 'red spot' can indeed be classified as unlucky cohorts with longer-term mortality increases from the overall

trend. The suppressing of the 'red spot' (and the A and P fluctuations and trends) enables us to even better detect cohort effects in APCD analysis with strong upward-right oriented fluctuations (fig 4).

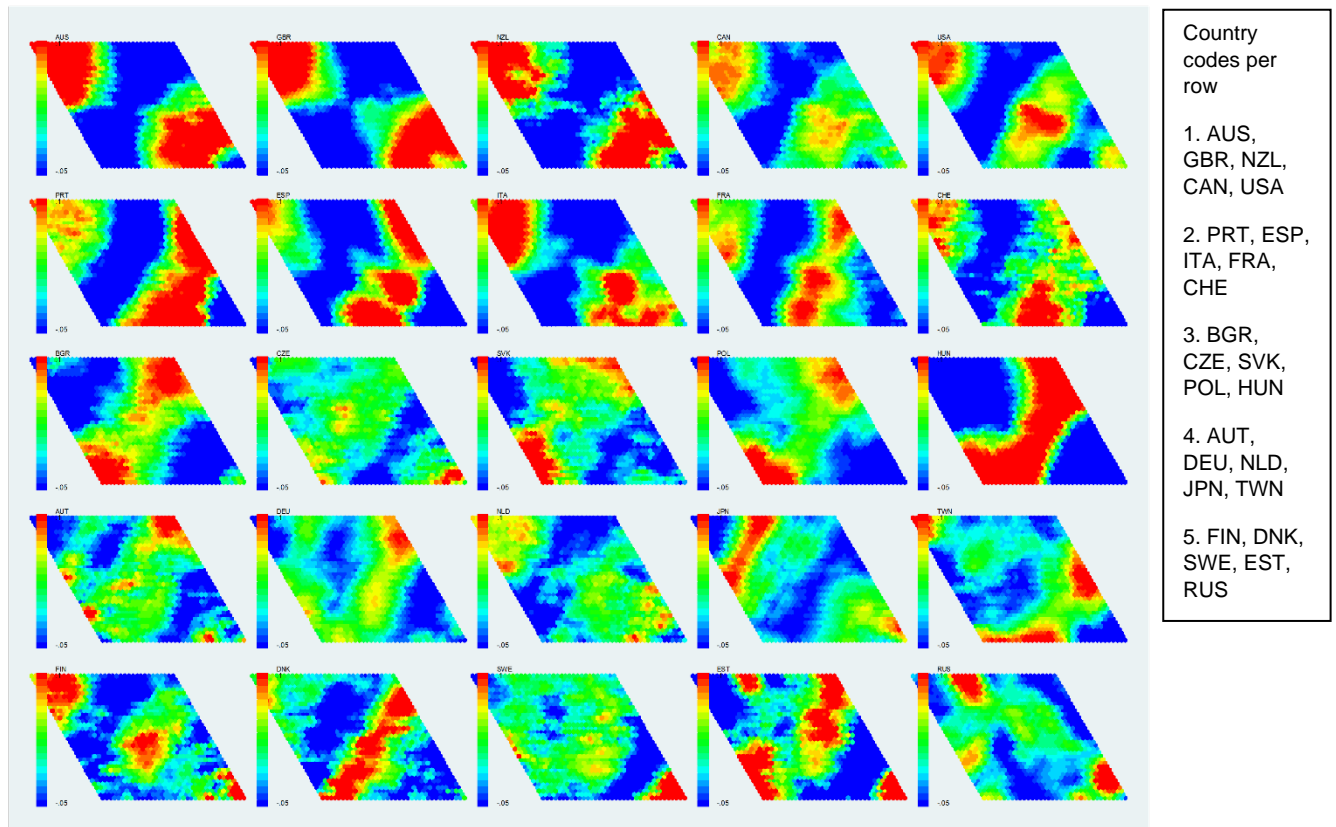


Figure 4. Residuals of A,P with the big red spot effect suppressed (age 32 in $p=1992$ / cohort 1960 +/-10 years).

Note: Net of the big red spot, the mortality structures are much more diagonally shaped in many countries and are better able to show healthier cohorts (e.g., U.S. residents born in 1945 or 1975) and unhealthier ones (those born in 1915, 1955, 1985).

Part II: Explaining the 'Red Spots' in Spain, Southern Europe, and the United States

The following analysis is driven by the assumption that the 'red spots' of similarly occurring public health crises in Spain, other southern European countries and, on a smaller scale, the

United States, Canada, Netherlands, and Denmark, may be driven by increases in HIV/AIDS mortality. Especially the Spanish case (Valdes & George, 2013), see discussion below, has demonstrated the magnitude of the AIDS epidemic, leading to quite severed losses in life expectancy. For our purposes, an exact re-running of analyses with WHO mortality-by-cause data is not possible, as deaths and population are only available in five-year intervals after age five². We therefore choose an aggregate correlation analysis by country relating the log of the average value of the red spot residual for ages 30-34 in 1992-1997 (y axis in Figure 5) to log-HIV/AIDS mortality rate in WHO (x axis in Figure 5). WHO provides HIV/AIDS mortality for 17 countries in the window of observation, of which we exclude four countries where values are very small (logs below a value of -10). In our selection of 13 countries (Australia, Austria, Canada, Denmark, France, Italy, Netherlands, New Zealand, Portugal, Spain, Switzerland, the U.K. and the U.S.) the correlational analysis shows that all-cause mortality increases are strongly related to increases in HIV/AIDS mortality, with 73 % of the variance in those measures explained (Figure 5). This is a rather high fraction considering that AIDS may not have always been reported as underlying cause of death, but rather other causes of death, such as suicide or accidents.

² In general, all-cause mortality can be considered as more robust than by-cause mortality for a general depiction of mortality trends since no bias due to questions of validity and reliability of medical death certificates needs to be considered. Especially for AIDS mortality it is known that unawareness of the disease in the beginnings of the outbreak as well as reporting other causes of death related to AIDS and other causes most likely led to a conservative reporting of the magnitude of the AIDS epidemic (Valdes & George, 2013).

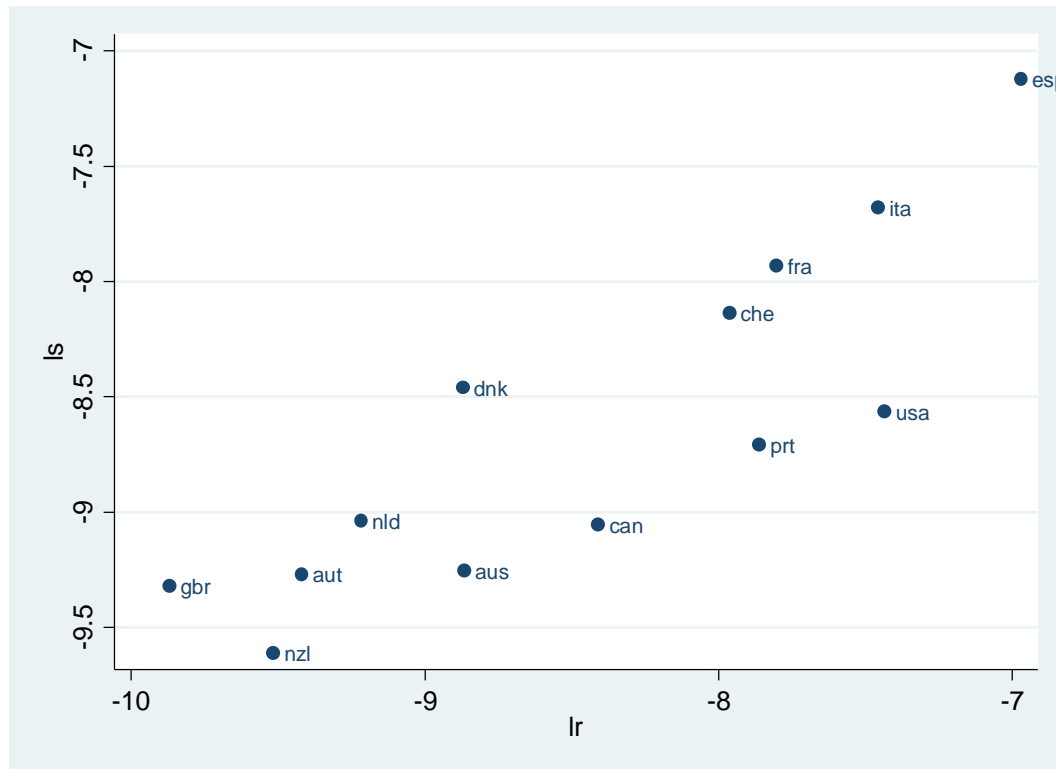


Figure 5. Correlation between $Y = \text{HMD log-excess mortality (intensity of the big red spot)}$ and $X = \text{WHO log-HIV/AIDS mortality for 13 countries, age group 30-34, and period 1992-1997}$.³

Discussion

We provide a tool to comprehensively analyze and graph mortality trends per birth cohort and calendar year, in order to detect deviations from the overall mortality trends, and to determine to which extent those deviations are a cohort or a period effect or both.

Explanation of findings

In an attempt to provide a fuller picture on what such a 'red spot' of elevated mortality levels may contain, we take the case of Spain and provide some more background to the specific public health crisis of the early 1990s. Indeed, Spanish young adults in the 1980s faced a 'perfect storm' of political and structural crises, economic downturns and associated diminished aspirations, alcohol and drug abuse and other risky health behaviors (Gómez-Redondo & Boe,

³ In the full paper, we will provide a detailed decomposition of the attributable rate of HIV/AIDS mortality to general mortality increases.

2005). This socioeconomic and health context was reinforced by the HIV outbreak, transmitted in Spain first mainly through shared use of (heroin) injection needles and leading to rather dramatic losses in life expectancy, mainly due to higher mortality at young ages (Valdes & George, 2013). Indeed, AIDS mortality increased along the early 1990s, and Figure 6 shows the peak for male AIDS incidence in 1994, male AIDS mortality in 1995 (for women the picture is less clear), with the cohorts of the early 1960s being the most affected for both genders. Other causes of mortality such as traffic accidents and drug and alcohol abuse were also contributing to the increased mortality of the cohorts in young adulthood at that time (Cleries et al., 2009). There was also a marked rise at that time in suicide mortality for young cohorts (Granizo, Guallar, & Rodriguez-Artalejo, 1996). We recently showed that the elevated suicide mortality patterns of the 1965-1975 cohort in Spain diminished over time and returned to normal levels again in the following decades (Chauvel, Leist, & Ponomarenko, 2016).

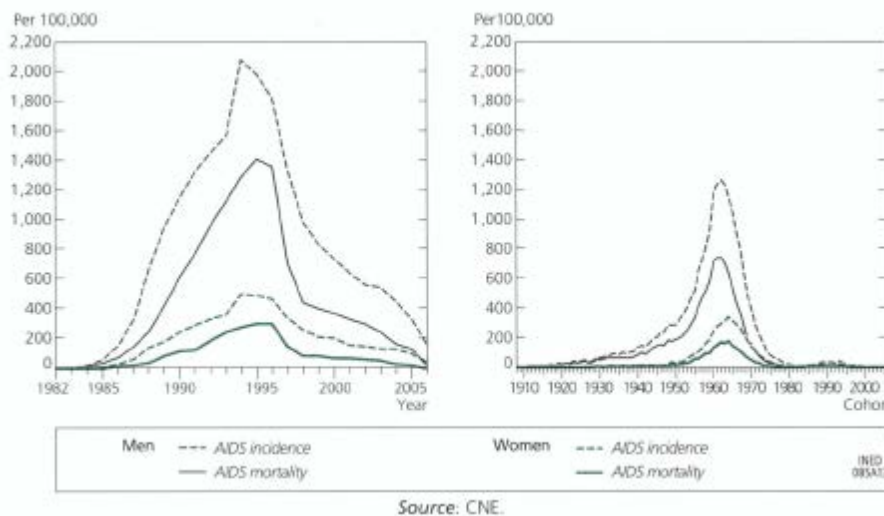


Figure 6. Total AIDS incidence rate (per 100,000) and total probability of dying from AIDS in Spain (per 100,000) for men and women, by year and by cohort, figure by Valdes & George, 2013) based on case data from the Spanish National Center for Epidemiology.

There is some evidence for HIV/AIDS incidence that other European countries have been affected by public health crises during this time as well (Houweling et al., 1999), with a geographic divide into southern European countries (France, Switzerland, Spain, Portugal) and

northern European countries (the Netherlands, Belgium, Germany, and the United Kingdom) (Valdes & George, 2013). Our method is the first to point out that Spain was not the only country experiencing a public health crisis in the early 1990s, but also Switzerland, France, Italy, and Portugal, and – on a smaller scale – the U.S., Canada, and Denmark.

Strengths and limitations

Strength of our method is that it is able to analyze and intuitively graph fine-grained mortality data per birth cohort and calendar year, and that it is able to give evidence of the magnitude of mortality deviations, especially with interest to the 'big red spot', the age-period interaction.

Important for the interpretation of the graphs is that the method detects public health crises with a certain delay. This means that all health behavior-related mortality, e.g. alcohol and drug abuse, and all conditions like HIV, Hepatitis, and war trauma with an incubation, latency or unawareness period are only visible years and sometimes even decades after their outbreak. Indeed, the detection of the 'big red spots' in the early 1990s in this paper points to large increase in rates of HIV infection and related improper public health management in the years and decade *before* the increase in mortality.

More detailed analyses on why unlucky birth cohorts with (unspecified) longer-term mortality disadvantages faced sudden increases in mortality need to be complemented by other data sources, firstly mortality by cause to get hints at possible causes for mortality crises as done in this paper. Also, micro-level data are helpful in order to investigate which population groups (education, ethnicity, marital status, or migrant status) were affected most in terms of unfavorable economic and social outcomes. As an illustration, we recently showed that the hypothesis of Easterlin, size of birth cohort matters, holds for suicide mortality of the late U.S. baby boomers (Chauvel, Leist, & Smith, 2016). However, additionally considering micro-level information from the CDC mortality data, we were able to show that increases in suicide of that cohort in 2010 were mostly attributable to white low-educated non-married men (Chauvel, Leist, & Smith, 2016).

Our method can be applied in all fields where large amounts of data need to be processed and illustrated in an intuitive way, and where deviations from trends are of particular interest. If quality of data permits, by-cause mortality analysis can equally be conducted. If micro-level data are available, mortality trends of population groups (e.g. by education, ethnicity, marital status) can be examined. Virtually all dichotomous outcomes and all higher levels (region, country, continent, globally) can be considered.

Conclusions

Our method is the first to systematically analyze and intuitively plot age-period interactions of excess mortality to detect localized mortality crises of one or more birth cohorts in one or more calendar years. Our findings suggest that APC analysis should always be complemented by exploiting residuals information from APCD analysis. We show that Spain was not the only country affected by a 'perfect storm' of multiple health challenges for young adults, but that Switzerland, France and Portugal faced similar situations, as well as the U.S., Canada, the Netherlands and Denmark, albeit on a smaller scale compared to their starting levels of mortality. Additional analyses show that much of the excess mortality can be attributed to increases in HIV/AIDS mortality in those countries. The method of detecting 'red spots' can be applied to mortality-by-cause, other dichotomous economic and social outcomes for virtually any aggregated or micro-level dataset to detect and estimate deviations from period and cohort trends.

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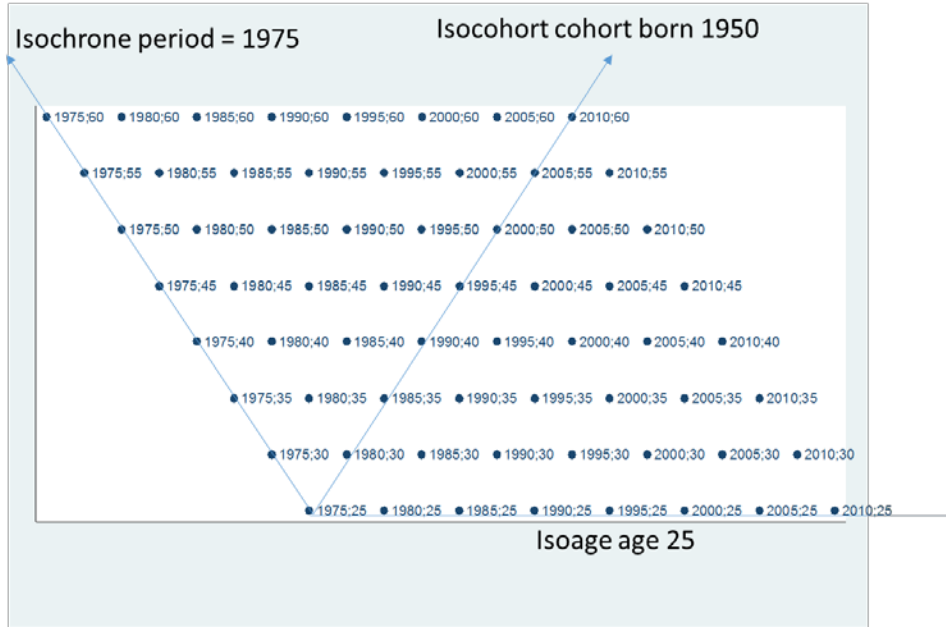
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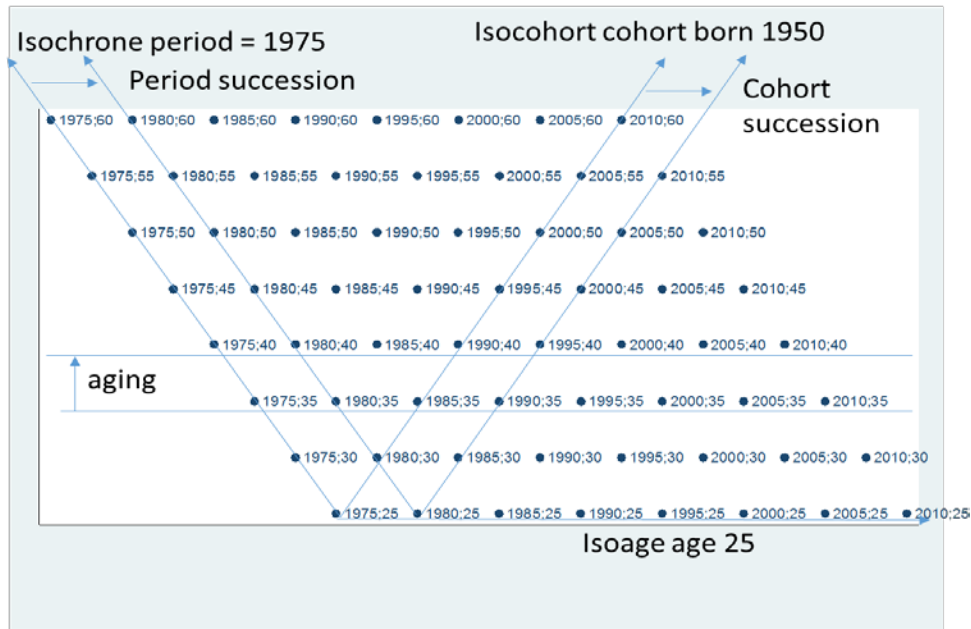
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Annex



Annex Figure 1. Equilateral Lexis diagram illustration.



Annex Figure 2. Equilateral Lexis with illustrations of period succession, cohort succession and aging.