

# Period-Based Mortality Change: Turning Points in Trends since 1950

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FROM THE mid-1950s to the late 1960s, mortality decline stalled in the United States, as it did in many other low-mortality countries. At the time, some observers speculated that progress against mortality had reached its limit and that the unprecedented fall in mortality experienced by these countries over the previous decades was coming to a halt or, at best, that mortality would decline at a much slower pace in the future (Spiegelman 1968; Gordon and Thom 1975). Against these dire prophecies, however, Eileen Crimmins (1981) showed that a steady, rapid decline in death rates resumed at the end of the 1960s in the United States. In the present article, we analyze the generality of this trend and its underlying causes within a number of high-income countries.

Crimmins argued that the similarity of the increase in survival across adult age groups in the United States indicated the likely influence of a common set of contemporaneous determinants (medical advances and changing lifestyles), thus suggesting that period rather than cohort processes were the driving forces behind the sudden resumption of the US mortality decline in the late 1960s. This conclusion, however, was contradicted by Yang Yang (2008), who claimed that reductions in US adult mortality from 1960 to 1999 were driven predominantly by cohort-based factors. A similar age-period-cohort analysis by Kristen Miller et al. (2011) concluded that recent reductions in US mortality for black and white adults are attributable mostly to earlier changes in cohort life histories rather than to contemporaneous events and circumstances. The conclusions of Yang and Miller et al. are consistent with evidence published by Samuel Preston and colleagues about the role of differential smoking behavior by cohort on historical mortality changes

in the United States and other countries (Preston and Wang 2006; Preston, Glei, and Wilmoth 2010). Yang and Miller et al.'s position also finds some support in Robert Fogel's theory of technophysio evolution, which implies significant cohort improvements in health capital and human physiological capacities over the course of the twentieth century (Fogel 2004).

In this article, we exploit data for a large set of low-mortality countries to follow up on Crimmins's analysis of the late-1960s major turning point in US mortality trends and to provide new evidence about the relative importance of period versus cohort factors as drivers of adult mortality change. We first investigate the generality of this discontinuity among high-income countries. Then, using age- and cause-specific mortality data, we seek to identify the age groups and disease categories that have made the largest contributions to the discontinuity and subsequent trends. We examine four broad categories of causes of death, namely heart diseases, cerebrovascular diseases, smoking-related cancers, and all other cancers. We focus on adults aged 40 and older because disruptions in mortality trends since 1950 for younger adults (aged 15–19 to 35–39) are weaker and often barely visible. When strong disruptions occur, they tend to reflect changes in mortality trends from external causes of death (e.g., accidents, homicide, suicide), which are beyond the scope of the present study. We conclude with a discussion of what can be learned about period versus cohort factors from such an analysis.

## Background

By definition, period-based factors are causal impacts attributable to current events—such as wars, epidemics, famines, economic recessions, scientific discoveries, political and legal changes—with immediate effects across all (or many) ages, whereas cohort-based factors are long-term impacts of experiences—such as behaviors or exposures—accumulated over a significant portion of the life cycle. While most observers can readily acknowledge the importance of period-specific influences on demographic processes, the substantive role of cohort effects requires a broader conceptual framework (Ryder 1965).

In mortality studies, the role of cohort-specific influences has mainly been explored by evaluating the after-effects of disadvantageous early-life events on subsequent death or survival probabilities. William Ogilvy Kermack and colleagues were the first to provide a persuasive demonstration of cohort effects in mortality (Kermack, McKendrick, and McKinlay 1934a, 1934b). Using data for England and Wales, the authors computed the ratio of death rates for ten-year age groups from 1851–1860 to 1921–1930 to age-specific death rates for 1841–1850. They found that these ratios were far more regular along cohorts than along periods<sup>1</sup> and concluded that the mortality experienced by cohorts of individuals in adulthood was largely determined

by the environmental conditions they had faced in the first 15 years of life.<sup>2</sup> The mechanism responsible for the predominant role of childhood conditions in adult mortality in the British case seems to have been the major decline in death rates from tuberculosis that occurred in England and Wales between the mid-1800s and early 1900s (Preston, Keyfitz, and Schoen 1972). Cohort influences on tuberculosis mortality have been extensively documented in the literature, beginning with Wade Hampton Frost's work based on tuberculosis death rate series for Massachusetts (Frost 1939).

Attempts to document the effects of tobacco consumption on mortality in later life have also pointed to the existence of strong cohort patterns (Doll et al. 1994, 2004; Preston and Wang 2006). A cohort's smoking history prior to age 40 affects its level of subsequent mortality, creating a cohort imprint on the trends in age-specific death rates. Several other empirical studies also support the idea that early-life conditions affect later-life mortality (for a review, see Elo and Preston 1992). But unlike for respiratory tuberculosis and smoking, the overall evidence remains mixed (for more recent contributions, see Barker 1995; Kannisto, Christensen, and Vaupel 1997; Bengtsson and Lindström 2000; Doblhammer 2004; Finch and Crimmins 2004; Barbi and Vaupel 2005; Gagnon and Mazan 2009; Cohen, Tillinghast, and Canudas-Romo 2010), suggesting that the effects could, in most cases, only be modest. In a number of recent papers, authors have in fact argued that period conditions may be more important than cohort conditions in determining contemporary national mortality trends in adults (Davey Smith and Kuh 2001; Vaupel, Carey, and Christensen 2003; Murphy 2010; Myrskylä 2010; Barbi and Camarda 2011).

Age-period-cohort (APC) analyses are widely used to partition observed variation in vital rates to ages, periods, and cohorts (Hobcraft, Menken, and Preston 1982). Although these models can lead to valid results in some situations (e.g., Wilmoth 1990; Preston and Wang 2006), the APC approach has serious limitations because of the exact mathematic connection between age, period, and cohort (i.e., cohort + age = period) (Wilmoth 2006). Most analyses of this type are not well-suited for determining the relative importance of cohort versus period factors as drivers of mortality change in an overarching perspective (Murphy 2010). In this study, we therefore pursue a simple approach to uncover the relative importance of cohort versus period factors as drivers of adult mortality change in high-income countries in the past 60 years. Specifically, we use two-slope regression models to assess the timing and magnitude of dominant turning points in death rate trends since 1950, making separate analyses by sex, age, and cause of death. We pay particular attention to the age pattern of temporal changes, given that period-based factors are experienced by all (or multiple) age cohorts around the same time, as opposed to cohort factors, which have more enduring effects but only for specific cohorts.

## Data and methods

### All-cause and cause-specific mortality data

We used two sources of data, namely the Human Mortality Database (HMD) (2011) for all-cause mortality statistics and the World Health Organization (WHO) Mortality Database (2011) for cause-specific data. All countries listed in the HMD are included in our analysis of all-cause mortality trends, except for Chile, Israel, Slovenia, and Taiwan because their data series are too short to provide the required long-term perspective. For the remaining 34 countries, the period covered starts in 1950 for the majority of those outside the former Soviet Union and ends with the most recent year available (online Appendix Table 1 provides a complete list of countries and years of available data<sup>3</sup>). The former East Germany and West Germany are treated separately throughout this study given their different mortality histories, especially prior to reunification in 1990 (Luy 2004). From the HMD we extracted death counts and estimates of population exposure by sex, five-year age groups (ages 40 and above), and single calendar years for each country.

Our analyses of cause-specific mortality trends rely on the official death counts by calendar year (starting in 1950 at the earliest), age (40 and above), sex, and underlying cause of death available in the WHO Mortality Database for all the countries in the all-cause mortality analysis, except for Eastern European countries and members of the former Soviet Union. The latter countries were excluded from this part of the analysis because of their incomplete cause-specific mortality series. For most of them, several years' worth of data are typically missing in the WHO database (online Appendix Table 1). In addition, for the years when data are available, the classification of deaths by cause follows a different scheme from that used for the other countries examined here, which makes the construction of comparable series difficult. In any event, these countries exhibit a markedly different pattern of all-cause mortality, suggesting the operation of a different set of factors driving their mortality change in recent decades.

The resulting data set covers 22 countries with complete cause-of-death series over four successive revisions of the International Classification of Diseases (from ICD-7 to ICD-10). We focused on diseases of the circulatory system<sup>4</sup> and on cancers, the currently leading causes of death above age 40 in all low-mortality countries. Taken together, these two broad groups of diseases have accounted for 40 to 80 percent of total mortality at ages 40 and above since 1950; this percentage varied considerably over time and across countries, though, and these two groups of causes typically account for a slightly larger share of total deaths for females than for males (online Appendix Tables 2A and 2B). Because of the wide range of risk factors involved in the etiology of the diseases included in these two groups, we tried to disaggregate them

into smaller, consistent categories that might have been differentially affected by period- versus cohort-related factors of change. However, because of the inconsistencies in the classification schemes used in the WHO database for the successive ICD periods, we were only able to construct four large disease categories selected for the relative uniformity in their definition over time.

These four categories are: heart diseases, cerebrovascular diseases, smoking-related cancers, and all other cancers. Our category of smoking-related cancers includes most cancers of the respiratory and digestive tracts, namely cancers of the lip, oral cavity, pharynx, esophagus, larynx, trachea, bronchus, and lung. The predominant role of cigarette smoking in the incidence of these cancers is well documented (Doll et al. 2004; Rogers et al. 2005; Thun et al. 1997; US Department of Health and Human Services 2004). While smoking also has some impact on the other types of cancers, additional factors are known to increase their risks independently from smoking. Mortality trends from these two groups of cancers are therefore not necessarily expected to be chronologically and structurally similar. The concordance table used for bridging the four revisions of the ICD is presented in online Appendix Table 3, with specific codes for each category in each time period.

## Methods

The purpose of the methods used in this study is to identify the major turning points in mortality trends and to compare them across all countries and, within each country, across age groups and disease categories. The goal is to uncover the patterns of mortality change and to assess their consistency with either the cohort- or the period-effects hypothesis.

As a first step, we studied all-cause mortality data to identify any sudden onset of mortality decline over the period of interest for the various countries. We computed age-standardized death rates for ages 40 and above by single calendar year, sex, and country using the total population (both sexes) of all HMD countries by five-year age groups in 1970 as the standard. To assess the timing and magnitude of the turning point in mortality trends, we fitted trend lines to these age-standardized death rates over time.

Several statistical approaches were explored. One approach was to estimate second derivatives at every calendar year in the domain of the mortality trend in order to measure how the rate of change of mortality varied over time. We fitted local regression lines over each successive and overlapping ten-year periods centered on each calendar year in the series (excluding the first and last five years available). Although this approach offered great flexibility, its outputs were difficult to interpret and to summarize, with little added value in terms of overall results compared to simpler methods. We also experimented with segmented regression models (Muggeo 2003), which are tailored for the estimation of broken-line relationships and for which

breakpoints are true model parameters. Confidence intervals for the single or multiple breakpoints come as by-products of such models, by contrast with simpler and more common approaches that use grid-search algorithms (e.g., based on  $R^2$  goodness-of-fit criteria) to locate turning points in trends. However, for segmented regression models, an initial guess must first be provided for the breakpoint parameter(s), which introduces undesirable subjectivity into the analysis. Since, with our data, the breakpoint parameter estimated with the segmented regression method was almost always identical to the turning point obtained using a grid-search algorithm based on  $R^2$  goodness-of-fit criteria, our preferred approach is the latter, which is simpler and less arbitrary.

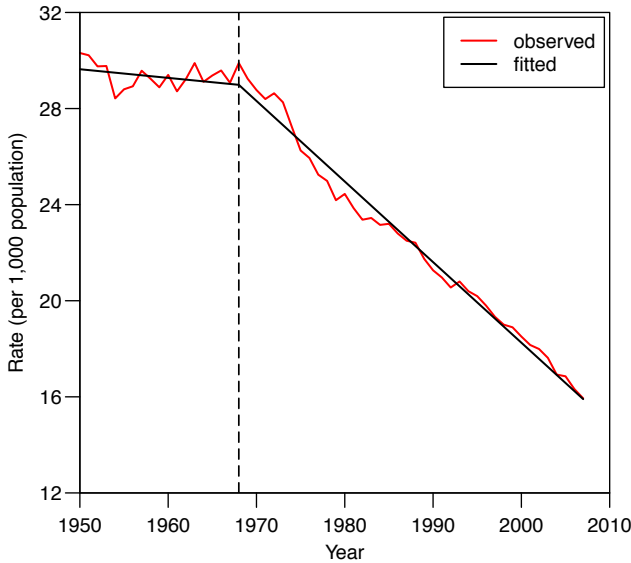
More specifically, we estimated two-slope regression models and interpreted the turning point for the slope as an indicator of the timing of the dominant discontinuity in the mortality trends. The turning point was allowed to occur in any calendar year throughout the period studied. We selected the turning point providing the best description of the data, that is, maximizing the goodness-of-fit in  $R^2$ . For example, Figure 1 shows that based on data for US males over the period 1950–2007, the dominant turning point for the slope in the all-cause age-standardized death rate (ASDR) occurred in 1968, yielding the following regression model:

$$\text{ASDR} = \beta_0 + \beta_1 (\text{year} - 1950) + \beta_2 (\text{year} - 1968) I_{\text{year} > 1968} + \epsilon,$$

where  $I_{\text{year} > 1968}$  is an indicator variable that equals one after 1968 and zero otherwise. Of the three model parameters,  $\beta_2$  is the most important one for our purpose, as it corresponds to the change in the slope of the mortality trend before and after the turning point. Therefore, a higher estimate for  $\beta_2$  (in absolute value) suggests a sharper mortality change, whereas a lower estimate suggests a milder mortality change. We used this parameter to assess the magnitude of the discontinuity in trend, distinguishing three levels: “high,” “moderate,” and “low.” Cut-off points for these three levels of magnitude were selected based on the sex-specific empirical distribution of  $\beta_2$  estimates for all countries, using the Fisher–Jenks algorithm (Fisher 1958; Slocum et al. 2005). This data classification method identifies cut-off points in a way that reduces the variance within classes while maximizing the variance between them. This series of analyses was carried out on all 34 initial countries.

We experimented with three- (and higher) slope regression models and found that they only occasionally provided a better description of the data than the comparable two-slope models. Furthermore, given our aim of identifying dominant turning points in mortality trends—uncovering general patterns rather than providing detailed descriptions of country-specific trends—two-slope regression models seemed preferable to more sophisticated models. The few instances where three-slope models clearly described the data better than the two-slope model are mentioned in the text.

**FIGURE 1** Age-standardized death rates in the United States with trend line, males aged 40 and above, 1950–2007



NOTES: The standard population corresponds to the total population (both sexes) of all HMD countries in 1970. The vertical dashed line indicates the year of the dominant turning point in the trend, according to the best-fitting two-slope regression model (by a criterion of maximum  $R^2$ ).  
SOURCE: Authors' calculations based on the HMD (2011).

We also fitted trend lines to all-cause age-specific death rates to determine whether the timing of the dominant turning point remains constant (or nearly constant) across all age groups considered, or whether the turning point shifts later in time at the same pace as the increase of age. The former case would provide evidence that period factors are the dominant force behind the mortality change because it would imply that all cohorts are affected simultaneously. In the latter case, cohort factors would appear as the main drivers since specific cohorts would experience a similar temporal change across a large portion of the life course.

In a second step, we analyzed cause-specific mortality data to identify the categories of diseases that made the largest contributions to the all-cause mortality change observed in the various countries. As we discussed earlier, the countries of Eastern Europe and the former Soviet Union (12 in total) were excluded from the cause-specific analysis because of a lack of appropriate data and because their all-cause mortality trends were fundamentally different. Cause-specific age-standardized death rates were first calculated for each calendar year and country by applying cause-specific and age-specific death fractions (computed from the WHO mortality data) to the age-specific

death rates (computed from the HMD). To attenuate fluctuations, the cause-of-death fractions were applied to smoothed all-cause death rates. Specifically, the smoothed death rates were calculated using death counts and population exposure estimates pooled over five-year windows centered on each successive calendar year in the series (excluding the first and last two years available). The two-slope regression model described above was similarly used to identify the dominant turning point in each of the four cause-specific age-standardized death rate trends over time for each sex, and to assess its timing and magnitude (“high,” “moderate,” or “low”). The range of values underlying each of the three levels of magnitude varies by sex and cause. The cut-off points for each sex and disease category were determined using the Fisher–Jenks algorithm on  $\beta_2$  estimates for all countries.

## Results

### Mortality for all causes of death and ages combined

Figure 2A displays country-specific trends in age-standardized death rates over time since 1950, or a few years later depending on data availability, for males aged 40 and above. It shows clearly that the sudden onset of mortality decline in the late 1960s was not restricted to the United States. Many other countries among those studied seem to have experienced similar sharp declines in the late 1960s or early 1970s. The regression analysis provides strong statistical evidence of this phenomenon in 12 countries in addition to the US, namely Australia, Belgium, Canada, Finland, France, Iceland, Luxembourg, New Zealand, Portugal, Spain, Switzerland, and West Germany (Table 1).<sup>5</sup>

The turning point occurred while these countries were experiencing widely varying levels of mortality at the start of the study period, with death rates ranging from 39 per thousand in Finland to 23 per thousand in Iceland in 1950 (Figure 2A). The initial level of mortality is uncorrelated with the timing of this dominant turning point in trend (Pearson’s correlation coefficient equal to  $-0.23$  with  $p = .446$ ). In many of these countries, just as in the United States, the decline took place after a long period of leveling-off in the mortality trend. In a few countries such as New Zealand and Luxembourg, it even marked the end of a recent rising trend. Unsurprisingly, these latter two countries, along with a few others, are characterized by a discontinuity of high magnitude (Table 1). In yet another group of countries, which includes Portugal and Switzerland, mortality was already on a declining trend since 1950, and although the pace of the decline was slower than after the turning point, the discontinuity was smaller. The direction of the mortality trend prior to the turning point—whether leveling-off, already decreasing slightly, or even increasing—is independent of the timing of the turning point.<sup>6</sup>

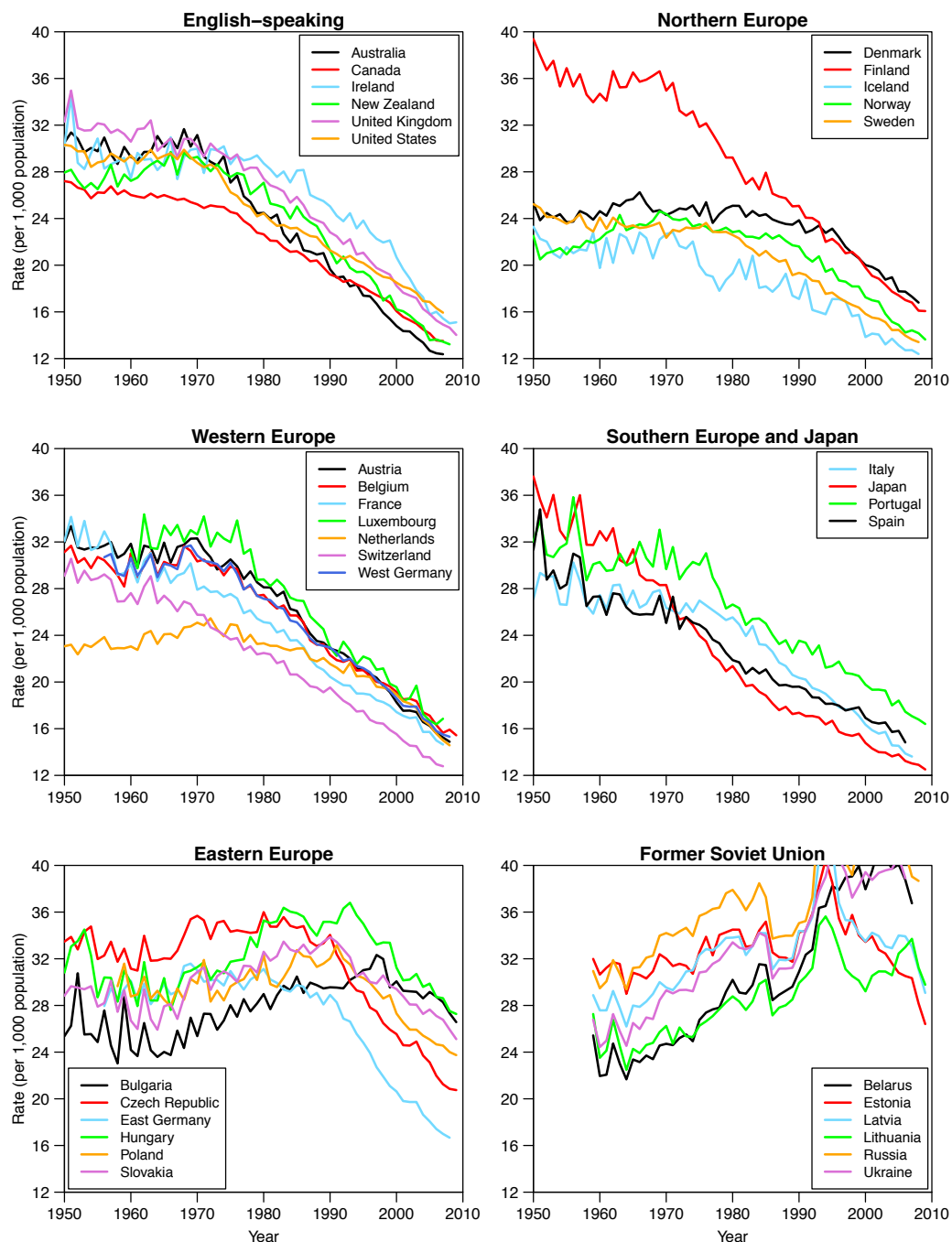
**TABLE 1** Timing and magnitude of the dominant turning point in the all-cause age-standardized death rate trend since around 1950, selected countries, males

| Late 1960s–early 1970s |                                    | Mid-1970s or later |                                    | Eastern Europe<br>(excl. former Soviet Union) |                                    |
|------------------------|------------------------------------|--------------------|------------------------------------|-----------------------------------------------|------------------------------------|
| Country                | Year of discontinuity <sup>a</sup> | Country            | Year of discontinuity <sup>a</sup> | Country                                       | Year of discontinuity <sup>a</sup> |
| United States          | 1968 (M)                           | Austria            | 1975 (H)                           | Czech Republic                                | 1985 (H)                           |
| Switzerland            | 1968 (L)                           | Netherlands        | 1976 (M)                           | East Germany                                  | 1986 (H)                           |
| Australia              | 1969 (H)                           | United Kingdom     | 1976 (M)                           | Slovakia                                      | 1990 (H)                           |
| Finland                | 1969 (M)                           | Italy              | 1977 (M)                           | Poland                                        | 1992 (H)                           |
| Spain                  | 1971 <sup>b</sup> (L)              | Sweden             | 1979 (L)                           | Hungary                                       | 1994 (H)                           |
| Luxembourg             | 1971 (H)                           | Norway             | 1981 (H)                           | Bulgaria                                      | 1998 (H)                           |
| Portugal               | 1971 (L)                           | Ireland            | 1985 (H)                           |                                               |                                    |
| Iceland                | 1971 (L)                           | Japan              | 1986 <sup>c</sup> (L)              |                                               |                                    |
| West Germany           | 1972 (H)                           | Denmark            | 1990 (M)                           |                                               |                                    |
| Belgium                | 1973 (M)                           |                    |                                    |                                               |                                    |
| Canada                 | 1973 (L)                           |                    |                                    |                                               |                                    |
| New Zealand            | 1974 (H)                           |                    |                                    |                                               |                                    |
| France                 | 1974 (L)                           |                    |                                    |                                               |                                    |

<sup>a</sup>Year that maximized goodness-of-fit (in R<sup>2</sup>) in the two-slope regression model for males in each country.  
<sup>b</sup>Based on five-year rates (i.e., pooled deaths and exposures over a five-year window), rather than annual age-standardized death rates, to avoid spurious influences of several pre-1970s sudden sharp increases in the trend (Figure 2A).  
<sup>c</sup>The death rate in Japan declined at a slower pace after 1986.  
NOTE: The letters in parentheses indicate the magnitude of the discontinuity, with cut-off points (see online Appendix Table 4) determined using the Fisher–Jenks algorithm: (H) high, (M) moderate, and (L) low.  
SOURCE: Authors’ calculations based on the HMD (2011).

A few additional countries, such as Ireland and Denmark, exhibit a similar pattern but are slightly delayed, as the discontinuity in their mortality trend occurs after the mid-1970s rather than around 1970 (Figure 2A). In fact, the regression analysis indicates that for seven countries (excluding those of Eastern Europe), namely Austria, Denmark, Ireland, Italy, the Netherlands, the United Kingdom, and Sweden, the major change in trend occurred between 1975 (Austria) and 1990 (Denmark) (Table 1). Norway as well belongs to this group when a two-slope regression model is used to describe its mortality trend since 1950. However, as seen in Figure 2A, there were actually two dominant turning points for Norway over the study period: the onset of mortality decline appears to have taken place around 1970 in Norway, as in the United States and the 12 other countries listed above, and then accelerated markedly toward the end of the 1980s. When a three-slope regression model is used to describe the mortality trend for Norwegian males over the past 60 years, the turning points providing the best fit (by a criterion of maximum R<sup>2</sup>) are 1969 and 1989. Japan is also worth mentioning because even though the regression analysis identifies a discontinuity in 1986, this year inaugurates a period of *slower* decline compared to the previous three-and-a-half decades,

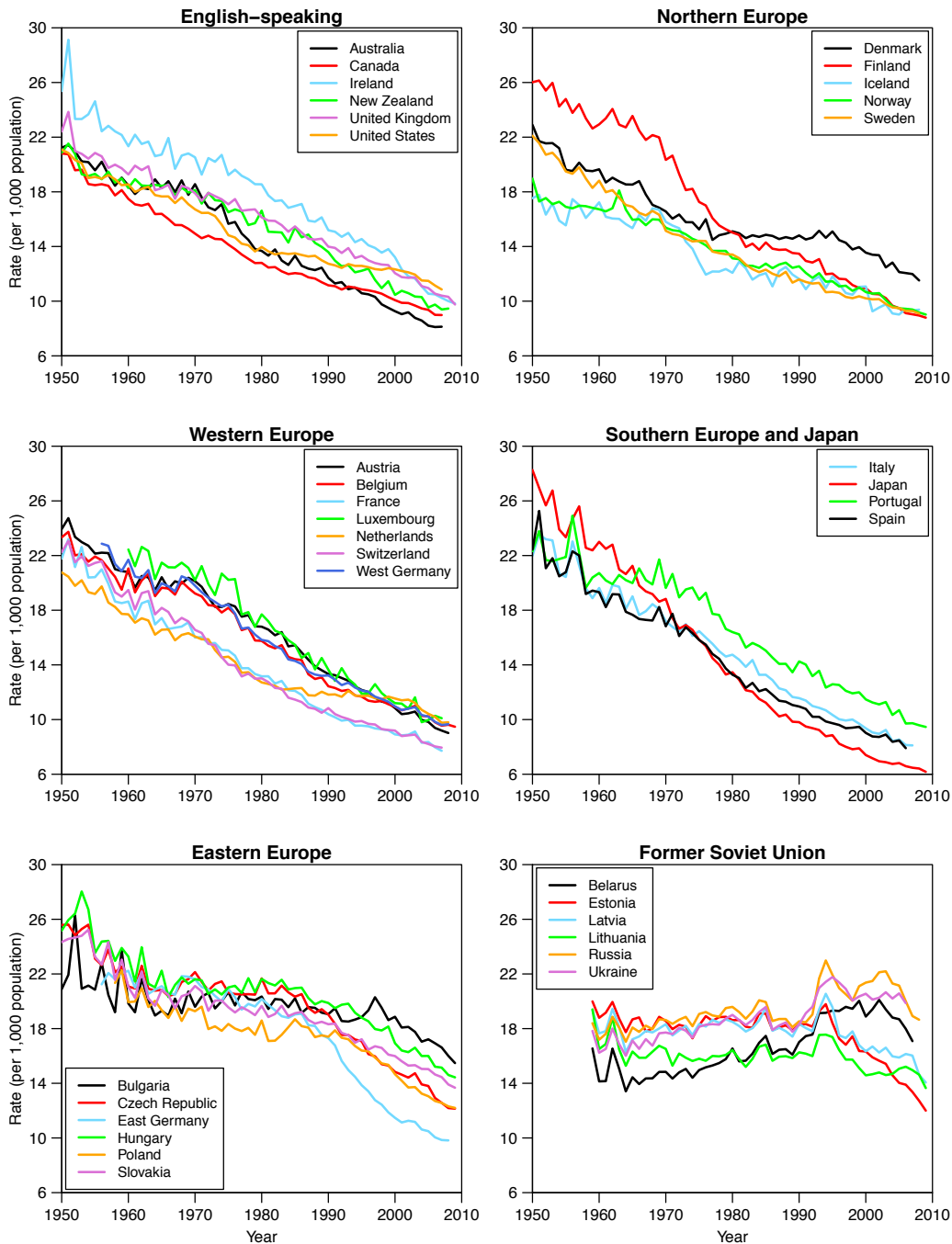
**FIGURE 2A All-cause age-standardized death rates in selected countries, males aged 40 and above, 1950–2009**



NOTE: The standard population corresponds to the total population (both sexes) of all HMD countries in 1970.

SOURCE: Authors' calculations based on the HMD (2011).

**FIGURE 2B All-cause age-standardized death rates in selected countries, females aged 40 and above, 1950–2009**



NOTE: The standard population corresponds to the total population (both sexes) of all HMD countries in 1970.  
SOURCE: Authors' calculations based on the HMD (2011).

during which the pace of mortality reduction was unusually rapid.<sup>7</sup> None of the other countries studied here displayed such a trend for males.

Most Eastern European countries exhibit an even later discontinuity in mortality trend, which was not observed before the 1990s (Figure 2A and Table 1). In every part of Eastern Europe, death rates systematically increased from the 1950s up to the point when they began to fall steeply, thus resulting in discontinuities of high magnitude. For instance, the Czech Republic and Hungary reached death rates as high as 36 per thousand before mortality trends started to decline rapidly in 1985 and 1994, respectively. Countries of the former Soviet Union have yet to experience this decline, except for Estonia and Latvia whose mortality has been declining sharply since the early 1990s, as was true for many Eastern European countries.

The overall pattern of age-standardized death rates for all causes of death combined for females is very different from the one described above for males (Figure 2B). In general, except for Eastern European countries outside of the former Soviet Union, disruptions in time-trends are weak and often barely visible. When such disruptions occur, they tend to mark the beginning of a period when mortality declines at a slower pace than previously, although there are a number of exceptions to this pattern. Luxembourg, Norway, and Portugal are typical of the countries<sup>8</sup> where female death rates fell more rapidly after the turning point rather than before it. The analysis of major turning points in all-cause mortality trends is thus much more relevant for males than for females. However, although all-cause mortality trends for females over the period since 1950 appear to be relatively uninformative, our analysis of cause-specific mortality trends has revealed more interesting patterns.

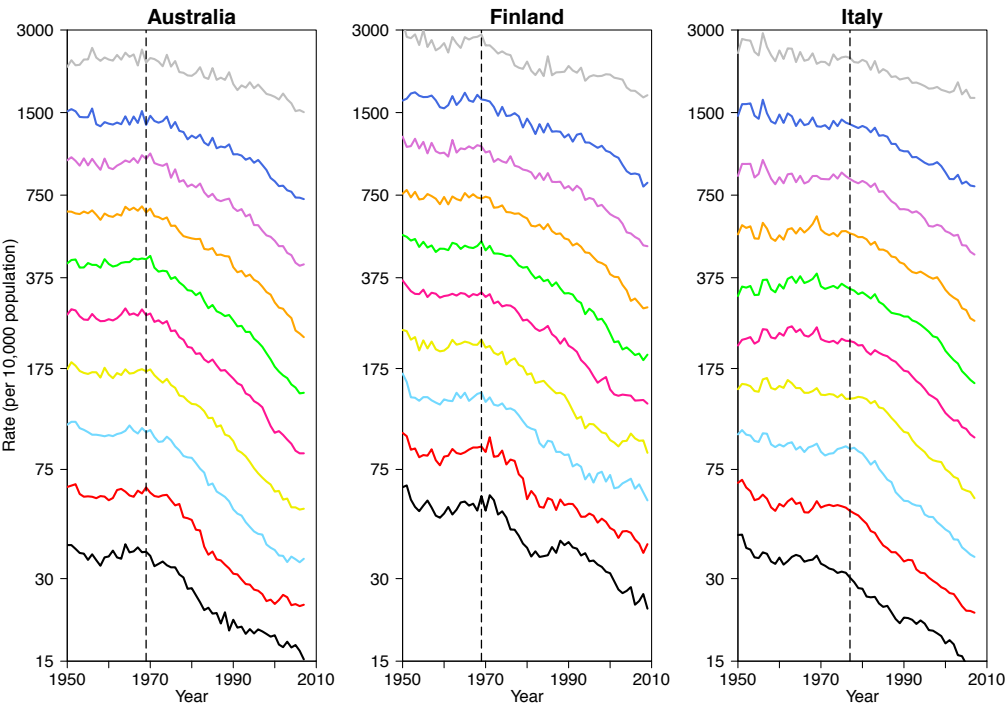
### Mortality for all causes of death by age

Before discussing broad cause-of-death categories, we review trends over time in age-specific death rates for males. These will indicate whether the sharp onset of mortality decline affected all age groups simultaneously—that is, across all cohorts at the same time, as opposed to occurring in successive calendar years in a way that would indicate that only selected cohorts were affected. Given the observations made earlier regarding data availability or specific circumstances in which the discontinuity took place, our analysis focuses hereafter on countries other than those of Eastern Europe and the former Soviet Union. Moreover, three countries representative of three distinct patterns were selected for illustration (i.e., in figures only), namely Australia, Finland, and Italy. In both Australia and Finland, the trend in male age-standardized death rates for all causes combined showed a strong and relatively early (1969) disruption, while in Italy the turning point was moderate in magnitude and occurred relatively late (1977) (Table 1). Australia appears to be highly representative of most English-speaking countries as well as of

many others, such as those in Western Europe (Figure 2A). Italy is also fairly representative of the other countries in its region, that is, Southern Europe. Finland, however, exhibits a distinct profile compared to the Nordic and other European and North American countries. It is characterized by a substantially higher level of mortality in years preceding the discontinuity, followed by a steady and rapid decline thereafter. This pattern, with some similarities to that of Japan, makes it an interesting case to review more thoroughly.

Figure 3 displays trends in age-specific death rates (on a semi-log scale) for males since 1950 in the three countries. The simultaneity in the onset of the more rapid decline in the late 1960s (Australia and Finland) or late 1970s (Italy) for all age groups is striking. Indeed, although the discontinuity in the mortality trends affected especially the population at ages 40–44 to 65–69, persons aged 70–84 also experienced an accelerated reduction of mortality risks in the three selected countries, as did the population above age 85. This pattern is similar to that found in the vast majority of countries studied and is confirmed by a statistical analysis conducted on all 22 countries.<sup>9</sup> These mor-

**FIGURE 3 All-cause age-specific death rates in Australia, Finland, and Italy, males aged 40 and above, 1950–2009**



NOTES: The distinctive lines designate the same age group in all three graphs. Lines are ordered from the lowest age group (40–44 years) at the bottom to the highest ones (80–84 years, and 85 and above) at the top. The vertical dashed line indicates the year of the dominant turning point in the age-standardized death rate trend for males in the given country (Table 1). SOURCE: Authors' calculations based on the HMD (2011).

tality trends by age for males thus provide evidence that the onset of mortality decline around 1970 was driven by period- rather than cohort-based factors, since it was experienced simultaneously across a broad age range rather than being concentrated in a single cohort or a narrow range of cohorts.

### Mortality by cause for all ages

Our analysis of mortality trends for all ages for each of the four large groups of diseases, presented in greater detail below, resulted in two general findings. First, for males, all death rate series show marked disruptions at some point over the past 60 years. The pattern is not as obvious for females, although there are many more countries exhibiting major changes in mortality trends for these four groups of diseases than when looking at all causes combined. Second, the timing of the dominant discontinuity in trends varies substantially depending on the type of diseases: while the onset of a major decline in cardiovascular mortality is typical of the 1960s and 1970s, changes in cancer mortality rarely take place before the 1980s and begin only in the 1990s for a majority of countries, especially for cancers not closely related to smoking.

*Cardiovascular diseases.* For males, the dominant turning point in mortality trends for all causes of death combined is clearly determined by changes in cardiovascular mortality. More than half of the study countries exhibit a high degree of coincidence in the timing and magnitude of the discontinuity in all-cause mortality on the one hand, and in heart disease and cerebrovascular disease mortality on the other (Tables 1 and 2A and 2B).<sup>10</sup> Perhaps surprisingly, the United States and Canada do not belong to this group because the regression results indicate that the dominant turning point in cerebrovascular mortality trends occurred later (around 1990 instead of 1970) and inaugurated a period of slower decline.<sup>11</sup> However, visual and statistical examination confirms that there were two major discontinuities in cerebrovascular mortality trends in these two countries. The first turning point, which marked the onset of an accelerated decline in cerebrovascular mortality, occurred just after 1970 in both countries (in 1971 for the United States and 1974 for Canada), while the second took place around 1990.

Between the two sub-categories of cardiovascular disorders, the proportion of deaths attributable to heart diseases is considerably larger than that from cerebrovascular diseases (online Appendix Tables 2A and 2B; Figure 4A), except for Japan and some countries in Southern Europe. Disruptions in trends for heart diseases also tend to be more pronounced than for cerebrovascular diseases among males, with the exception of a few countries in Western Europe (Belgium in particular) and Southern Europe (Portugal and Spain) and especially Japan. It is notable that the decline in cerebrovascular disease mortality in Japan was also extremely rapid—the age-standardized death rate declined by about three-quarters between the 1960s and 1990s—compared to what was observed for other diseases and in other locations.

For females, the pattern is much less consistent than for males across geographic areas. In most countries, particularly in English-speaking countries and to a smaller extent in Western Europe, the declining mortality trend was fairly steady for both groups of cardiovascular diseases over the whole period under study. For those countries with discontinuities of greater magnitude, changes in trends are more pronounced for heart diseases than for cerebrovascular diseases in most of Northern Europe (Finland and Norway, especially) while the opposite is typically observed in Southern Europe (at least in Portugal and Spain). Japan also follows the Southern European pattern but to an even larger extent, as the decline in female mortality from cerebrovascular diseases was especially steep in that country (though less than for males).

*Cancer.* Results of the regression analysis in Tables 2A and 2B for cancer mortality trends indicate that, as in the case of cardiovascular mortality, major disruptions took place for both males and females over the past 60 years in nearly all countries examined. In most instances, turning points in cancer trends occurred in the 1980s and 1990s, but the impact of these changes is not visible in the all-cause mortality series (Figures 2A and 2B) because opposite trends in the two groups of cancers cancel each other out. For females especially, trends have been clearly diverging for these two groups: whereas death rates from smoking-related cancers have increased in all countries since 1950 (except Finland, where they have declined up to the mid-1970s and only moderately increased thereafter, as shown in Figure 4B), mortality from other forms of cancers has declined since the 1960s or earlier everywhere (except Ireland and New Zealand, where the downturn began around 1990).

For males, the magnitude of the dominant turning point in cancer mortality trends is more pronounced overall for smoking-related cancers than for all other cancers (Table 2A and Figure 4A). After a long period of sustained increase, mortality from the former group of diseases has been exhibiting a steep decline since the turning point. The timing of the change in trend is associated with the steepness of the mortality decline, such that countries where the decline started in the 1980s (or earlier) experienced a more sustained fall in tobacco-related mortality than the few countries where the break point occurred later (Norway, Iceland, Portugal, and Japan).<sup>12</sup> Austria and Sweden are exceptions to this pattern. In these two countries, the mortality decline in smoking-related cancers was initiated earlier and was less pronounced than in other countries (Table 2A). In Sweden, however, as in Norway, Iceland, Portugal, and Japan, mortality from these types of cancers never reached the high levels recorded in the other countries under study (online Appendix Tables 2A and 2B).

These findings are consistent with the literature on the effect of smoking on international trends in adult mortality. For example, Preston, Gleij, and Wilmoth (2010) examined a similar set of 21 high-income countries and found that the lowest estimated proportion of deaths above age 50 attributable to smoking among males in 1955 and 1980 occurred in the

**TABLE 2A Timing and magnitude of the dominant turning point<sup>a</sup> in the cause-specific age-standardized death rate trend since around 1950, selected high-income countries, males**

| Region/<br>country      | Heart<br>diseases     | Cerebro-<br>vascular<br>diseases | Smoking-<br>related<br>cancers <sup>b</sup> | All other<br>cancers |
|-------------------------|-----------------------|----------------------------------|---------------------------------------------|----------------------|
| <b>English-speaking</b> |                       |                                  |                                             |                      |
| Australia               | 1967 (H)              | 1969 (M)                         | 1980 (H)                                    | 1994 (M)             |
| Canada                  | 1966 (M)              | 1989 <sup>†</sup> (L)            | 1986 (H)                                    | 1992 (L)             |
| Ireland                 | 1984 (H)              | 1971 (M)                         | 1985 (M)                                    | 1996 (H)             |
| New Zealand             | 1970 (H)              | 1972 (M)                         | 1981 (H)                                    | 1994 (H)             |
| United Kingdom          | 1980 (M)              | 1965 (L)                         | 1975 (H)                                    | 1994 (M)             |
| United States           | 1966 (M)              | 1990 <sup>†</sup> (L)            | 1983 (M)                                    | 1993 (M)             |
| <b>Northern Europe</b>  |                       |                                  |                                             |                      |
| Denmark                 | 1978 (H)              | 1977 <sup>†</sup> (L)            | 1984 (M)                                    | 1997 (L)             |
| Finland                 | 1969 (H)              | 1964 (L)                         | 1972 (H)                                    | 1997 (L)             |
| Iceland                 | 1980 (H)              | ..                               | 1996 (M)                                    | ..                   |
| Norway                  | 1978 (H)              | 1966 (M)                         | 1990 (L)                                    | 1994 (M)             |
| Sweden                  | 1979 (H)              | 1970 <sup>†</sup> (L)            | 1978 (L)                                    | 1975 (L)             |
| <b>Western Europe</b>   |                       |                                  |                                             |                      |
| Austria                 | 1982 (M)              | 1974 (M)                         | 1979 (L)                                    | 1992 (L)             |
| Belgium                 | 1970 (H)              | 1969 (H)                         | 1983 (H)                                    | 1982 (M)             |
| France                  | 1976 (L)              | 1971 (L)                         | 1981 (H)                                    | 1990 (H)             |
| Luxembourg              | —                     | 1982 (H)                         | 1986 (H)                                    | 1987 (M)             |
| Netherlands             | 1976 (M)              | 1955 (M)                         | 1981 (H)                                    | 1988 (M)             |
| Switzerland             | 1982 (L)              | ..                               | 1979 (M)                                    | —                    |
| West Germany            | 1979 (H)              | 1970 (L)                         | —                                           | —                    |
| <b>Southern Europe</b>  |                       |                                  |                                             |                      |
| Italy                   | 1974 (M)              | 1979 (L)                         | 1985 (H)                                    | 1989 (H)             |
| Portugal                | 1959 <sup>†</sup> (L) | 1975 (H)                         | 1993 (L)                                    | 1964 (M)             |
| Spain                   | 1977 (L)              | 1974 (M)                         | 1994 (M)                                    | 1961 (H)             |
| <b>East Asia</b>        |                       |                                  |                                             |                      |
| Japan                   | 1969 (L)              | 1962 (H)                         | 1992 (L)                                    | 1997 (H)             |

<sup>a</sup>Calendar year that maximizes goodness-of-fit (in  $R^2$ ) in the two-slope regression model for each disease category and country.

<sup>b</sup>Includes all deaths from malignant neoplasms of lip, oral cavity, pharynx, esophagus, larynx, trachea, bronchus, and lung as the underlying cause.

NOTES: “—” indicates that the data series were too short to perform the regression analysis.

“..” indicates that the two-slope regression model did not provide a better description of the data than the comparable one-slope model (F-tests for nested models resulting in  $p > .01$ ).

“<sup>†</sup>” indicates that the death rate for the specific cause-of-death category declined less rapidly after the turning point.

The letters in parentheses indicate the magnitude of the discontinuity, with sex- and cause-specific cut-off points (see online Appendix Table 4) determined using the Fisher-Jenks algorithm: (H) high, (M) moderate, and (L) low. SOURCE: Authors’ calculations based on the HMD (2011) and WHO Mortality Database (2011).

same countries emphasized above (Norway, Iceland, Portugal, Japan, and Sweden). Moreover, their study shows that countries with the highest proportion of smoking-attributable deaths for males in 1955 (Finland, the

**TABLE 2B Timing and magnitude of the dominant turning point<sup>a</sup> in the cause-specific age-standardized death rate trend since around 1950, selected high-income countries, females**

| Region/<br>country      | Heart<br>diseases     | Cerebro-<br>vascular<br>diseases | Smoking-<br>related<br>cancers <sup>b</sup> | All other<br>cancers |
|-------------------------|-----------------------|----------------------------------|---------------------------------------------|----------------------|
| <b>English-speaking</b> |                       |                                  |                                             |                      |
| Australia               | 1967 (H)              | 1970 (M)                         | 1994 (M)                                    | 1993 (M)             |
| Canada                  | 1991 <sup>†</sup> (L) | 1984 <sup>†</sup> (L)            | 1966 <sup>‡</sup> (H)                       | 1992 (L)             |
| Ireland                 | 1995 (M)              | 1970 (M)                         | 1988 (H)                                    | 1991 (H)             |
| New Zealand             | 1985 (L)              | 1971 (M)                         | 1991 (M)                                    | 1991 (H)             |
| United Kingdom          | 1995 (L)              | 1964 (L)                         | 1990 (H)                                    | 1990 (M)             |
| United States           | 1990 <sup>†</sup> (L) | 1989 <sup>†</sup> (M)            | 1996 (H)                                    | 1996 (L)             |
| <b>Northern Europe</b>  |                       |                                  |                                             |                      |
| Denmark                 | 1993 (L)              | 1976 <sup>†</sup> (M)            | 1969 <sup>‡</sup> (H)                       | 2000 (H)             |
| Finland                 | 1963 (H)              | 1981 <sup>†</sup> (M)            | 1970 <sup>‡</sup> (M)                       | 1993 (L)             |
| Iceland                 | 1987 (M)              | 1982 <sup>†</sup> (M)            | ..                                          | 1962 (H)             |
| Norway                  | 1963 (H)              | 1959 (M)                         | 1977 <sup>‡</sup> (H)                       | 1995 (M)             |
| Sweden                  | 1962 (M)              | 1971 <sup>†</sup> (M)            | 1977 <sup>‡</sup> (M)                       | 1974 (L)             |
| <b>Western Europe</b>   |                       |                                  |                                             |                      |
| Austria                 | 1982 (M)              | 1974 (M)                         | 1977 <sup>†</sup> (L)                       | 1990 (L)             |
| Belgium                 | 1967 (M)              | 1970 (H)                         | 1978 <sup>‡</sup> (L)                       | 1988 (L)             |
| France                  | 1981 (L)              | 1972 (L)                         | 1983 <sup>‡</sup> (L)                       | 1974 (L)             |
| Luxembourg              | —                     | 1982 (H)                         | ..                                          | 1994 (H)             |
| Netherlands             | 1972 (L)              | 1983 <sup>†</sup> (L)            | 1979 <sup>‡</sup> (H)                       | 1968 (L)             |
| Switzerland             | 1973 <sup>†</sup> (L) | ..                               | 1974 <sup>†</sup> (M)                       | —                    |
| West Germany            | 1974 (H)              | 1966 (L)                         | 1977 <sup>†</sup> (M)                       | —                    |
| <b>Southern Europe</b>  |                       |                                  |                                             |                      |
| Italy                   | 1963 (M)              | 1982 (L)                         | 1992 (L)                                    | 1989 (M)             |
| Portugal                | 1973 <sup>†</sup> (M) | 1974 (H)                         | 1968 (L)                                    | 1965 (M)             |
| Spain                   | 1976 (L)              | 1974 (M)                         | 1961 (M)                                    | 1962 (H)             |
| <b>East Asia</b>        |                       |                                  |                                             |                      |
| Japan                   | 1973 (M)              | 1963 (H)                         | 1984 (L)                                    | 1960 (M)             |

<sup>a</sup>Calendar year that maximizes goodness-of-fit (in R<sup>2</sup>) in the two-slope regression model for each disease category and country.

<sup>b</sup>Includes all deaths from malignant neoplasms of lip, oral cavity, pharynx, esophagus, larynx, trachea, bronchus, and lung as the underlying cause.

NOTES: “—” indicates that the data series were too short to perform the regression analysis.

“..” indicates that the two-slope regression model did not provide a better description of the data than the comparable one-slope model (F-tests for nested models resulting in  $p > .01$ ).

“†” indicates that the death rate for the specific cause-of-death category declined less rapidly after the turning point.

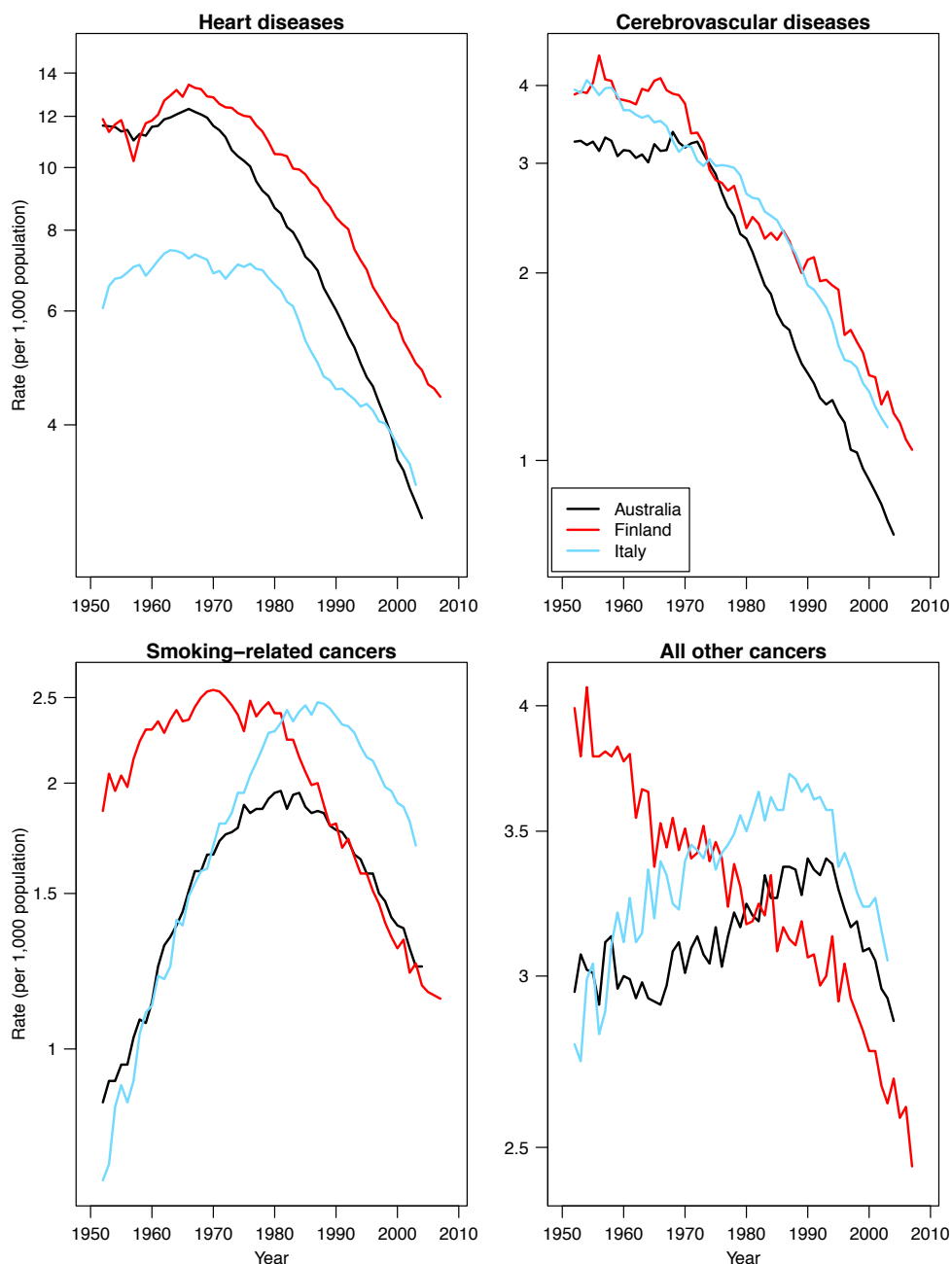
“‡” indicates that the death rate for the specific cause-of-death category increased more rapidly or started to increase after the turning point.

The letters in parentheses indicate the magnitude of the discontinuity, with sex- and cause-specific cut-off points (see online Appendix Table 4) determined using the Fisher–Jenks algorithm: (H) high, (M) moderate, and (L) low.

SOURCE: Authors’ calculations based on the HMD (2011) and WHO Mortality Database (2011).

United Kingdom, Austria, the Netherlands, Switzerland, and Belgium) also experienced the largest decline in this proportion between 1980 and 2003.

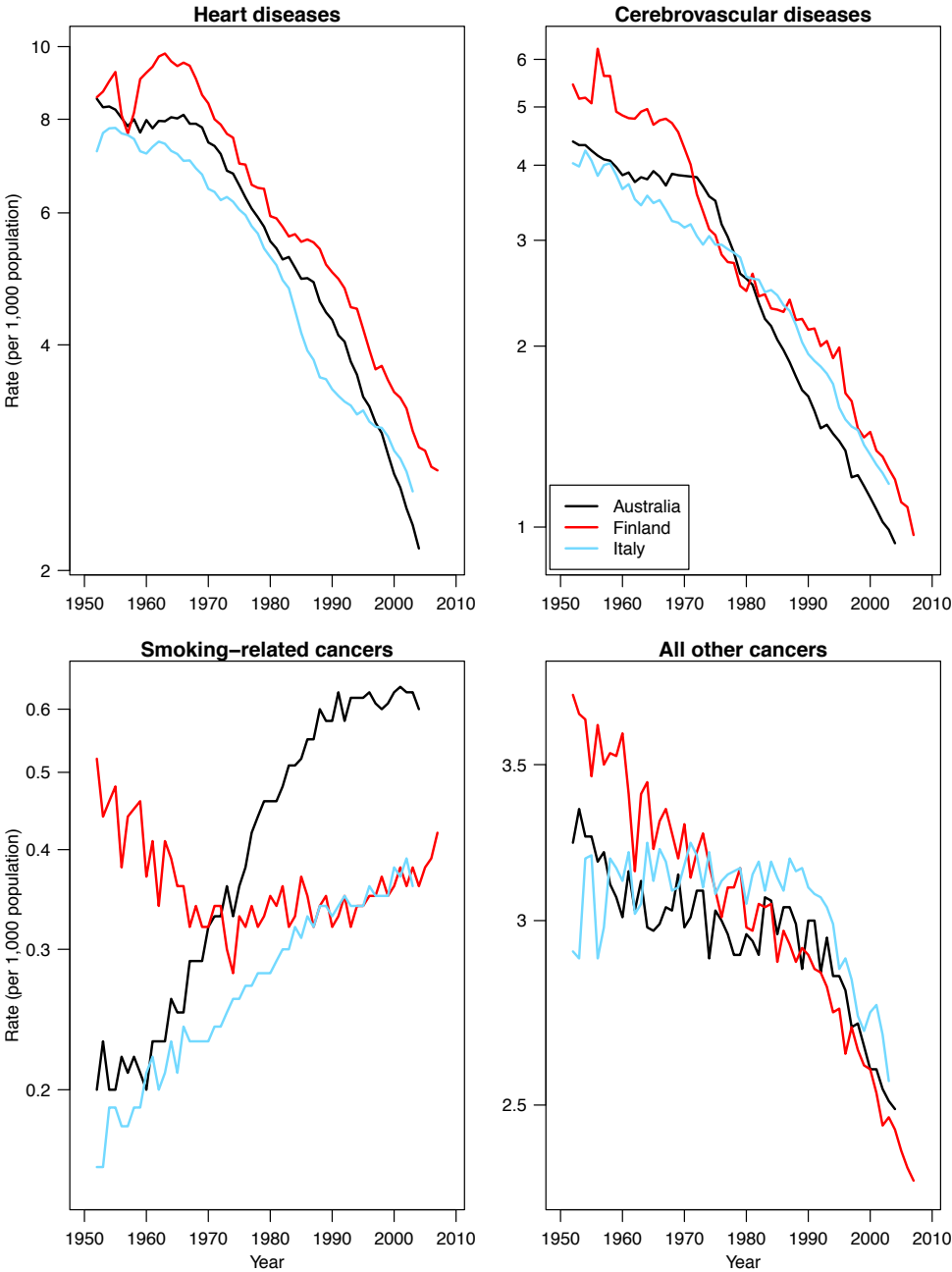
**FIGURE 4A Age-standardized death rates for selected causes of death in Australia, Finland, and Italy, males aged 40 and above, 1952–2007**



NOTES: The standard population corresponds to the total population (both sexes) of all HMD countries in 1970. The smoking-related cancer death rate includes all deaths from malignant neoplasms of lip, oral cavity, pharynx, esophagus, larynx, trachea, bronchus, and lung as the underlying cause.

SOURCE: Authors' calculations based on the HMD (2011) and WHO Mortality Database (2011).

**FIGURE 4B** Age-standardized death rates for selected causes of death in Australia, Finland, and Italy, females aged 40 and above, 1952–2007



NOTES: The standard population corresponds to the total population (both sexes) of all HMD countries in 1970. The smoking-related cancer death rate includes all deaths from malignant neoplasms of lip, oral cavity, pharynx, esophagus, larynx, trachea, bronchus, and lung as the underlying cause.  
SOURCE: Authors' calculations based on the HMD (2011) and WHO Mortality Database (2011).

These various results suggest that high-income countries with the earliest smoking epidemics for males are also those where the impact of smoking on mortality reached the highest level and where the epidemics receded the earliest and the fastest.

For all other cancers, the recent decline in mortality for males typically began in the 1990s, usually following an extended period of leveling-off or moderate increase in trend (Table 2A and Figure 4A). The main exception here is Portugal, the sole country in this study to exhibit an increase, which decelerated slightly from the early 1960s onward, but still with no sign of decline. Finland and Austria are also distinct in that they experienced a continuous fall in mortality rates from all other cancers throughout the period, with an accelerated decline starting in 1997 and 1992, respectively.

The gap between males and females in cancer mortality, as one would expect, is much larger for smoking-related cancers than for all other cancers (Tables 2A and 2B and Figures 4A and 4B), reflecting very different trends in tobacco consumption between males and females over the past 50–60 years. For females, the typical trend in smoking-related cancers is a continuous increase over the period under study as mentioned above. In Western and Northern Europe (except Finland), the dominant discontinuity in trends occurred during the 1970s and inaugurated a change from a low and fairly stable death rate to a rising death rate. In Finland, Japan, and Southern Europe, mortality trends from smoking-related cancers since the 1950s have either remained at a very low level or have increased slightly. In most English-speaking countries, mortality from smoking-related cancers increased from the 1950s up to the early 1990s but then reached a plateau at a level two to six times higher than 40 years earlier.

Trends in mortality from all other cancers also exhibit substantial differences by sex, though less distinct than for smoking-related cancers. Females, like males, have experienced substantial declines in this type of mortality since the 1990s in most countries under study (Table 2B and Figure 4B). However, by contrast with males for whom the downturn generally followed a period of moderate increase or leveling-off in trend, mortality was already declining prior to the turning point for females in many countries of Northern and Western Europe, plus the United States, Canada, and Australia, and it accelerated markedly thereafter. In Spain, Portugal, and Japan, female mortality exhibited a major change in trend in the 1960s instead of the 1990s, when their death rates for all other cancers stopped increasing and began to fall.

### Age-specific mortality by cause

We now examine mortality trends by age for the four groups of diseases, in order to determine whether the mortality changes described above affected many age groups simultaneously as opposed to occurring in successive calendar years with advancing age. Again, the former would provide evidence

that period effects were the main forces underlying the given major mortality change, while the latter would support cohort effects.

As was true for the results of the analysis for all-cause age-specific death rates (Figure 3), the concurrence in the timing of the onset of the decline in cardiovascular mortality (or the onset of an accelerated decline) for most age groups is striking for both males and females in the three illustration countries (Figures 5A and 5B). The simultaneity in the change in trends is obvious for both heart disease mortality and cerebrovascular mortality, except perhaps for Finnish females for whom the pattern is not as clear. Results for the vast majority of the 22 countries studied are very similar to those presented here (see endnote 9). These cardiovascular mortality trends by age and sex thus provide additional evidence that period effects were the main drivers in the precipitous decline of mortality that occurred in several Western countries around 1970.

In contrast, trends in mortality from smoking-related cancers seem to be at least partly cohort-driven to the extent that the dominant turning point appears to shift toward later calendar years with advancing age in many countries, especially for males (Figure 5A). Corresponding trends for females (Figure 5B) are not as clear as those for males, in part because of the larger fluctuations due to small numbers that tend to blur the pattern. Female death rates from smoking-related cancers, though increasing, remain at a fairly low level. If the recent change in mortality trends for smoking-related cancers among males was principally cohort driven, then the sudden onset of the decline (following either an increasing or stagnating trend) for each five-year age group would occur about five years later than for the previous age group (i.e., along a diagonal line), yielding a total time lag of about 40 years between the youngest (40–44) and oldest (80–84) males. Instead, Figure 5A suggests a much narrower lag in all three countries than expected under the assumption of a strict cohort effect. This observation is further confirmed by the results presented in Table 3, which indicate the year of the dominant turning point in the given age- and cause-specific mortality trend, according

**TABLE 3    Timing of the dominant turning point<sup>a</sup> in the age-specific smoking-related cancer death rate trend since around 1950 in Australia, Italy, and Finland, males**

| Age group | Australia | Italy | Finland |
|-----------|-----------|-------|---------|
| 40–54     | 1976      | 1981  | 1961    |
| 55–69     | 1981      | 1987  | 1970    |
| 70–84     | 1980      | 1985  | 1979    |

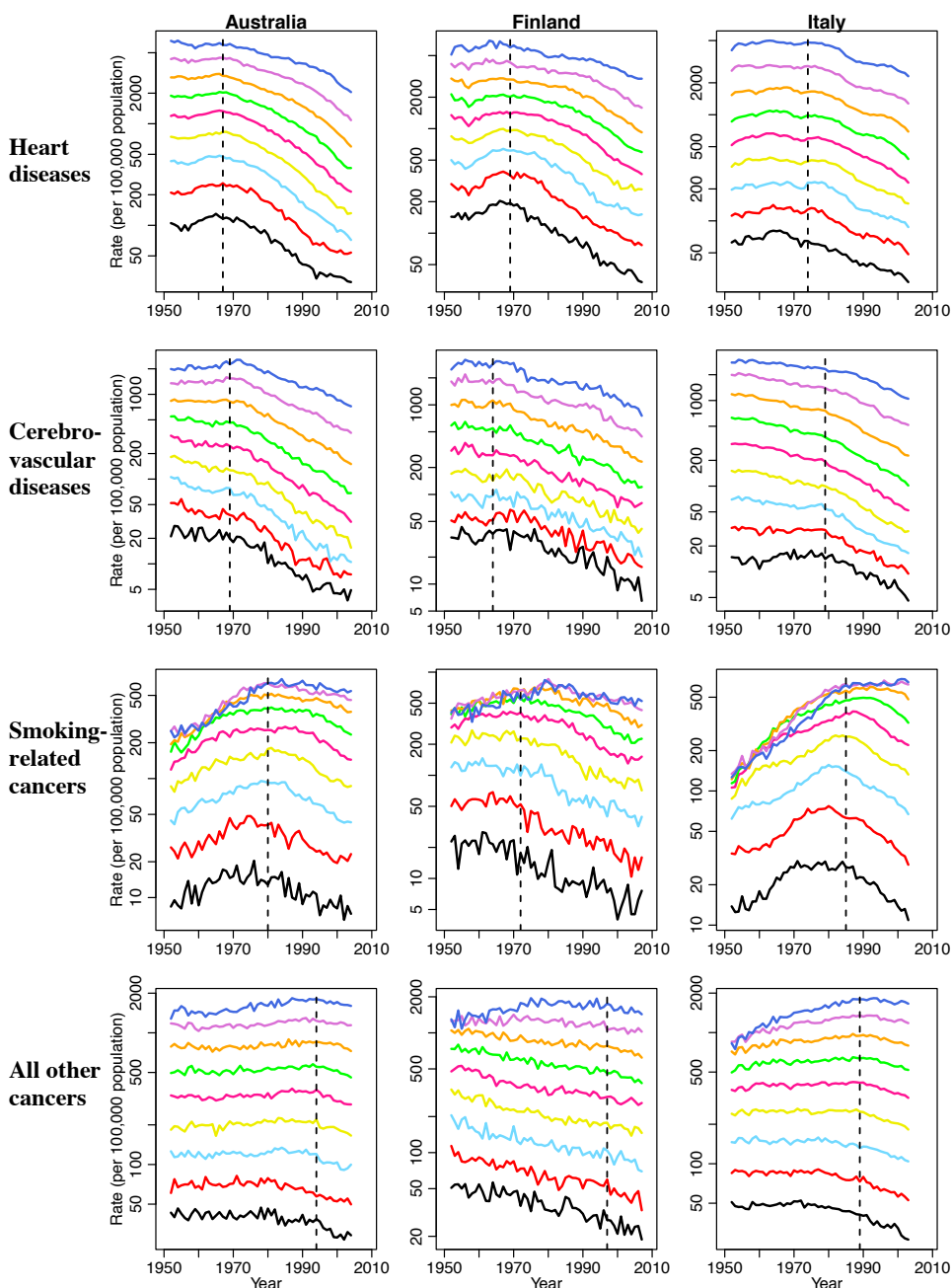
<sup>a</sup>Calendar year that maximizes goodness-of-fit (in R<sup>2</sup>) in the two-slope regression model for each age group and country.

NOTES: The smoking-related cancer death rate includes all deaths from malignant neoplasms of lip, oral cavity, pharynx, esophagus, larynx, trachea, bronchus, and lung as the underlying cause.

Because of large fluctuations in death rate trends for five-year age groups (among Finnish males in particular), we provide results for 15-year age groups.

SOURCE: Authors' calculations based on the HMD (2011) and WHO Mortality Database (2011).

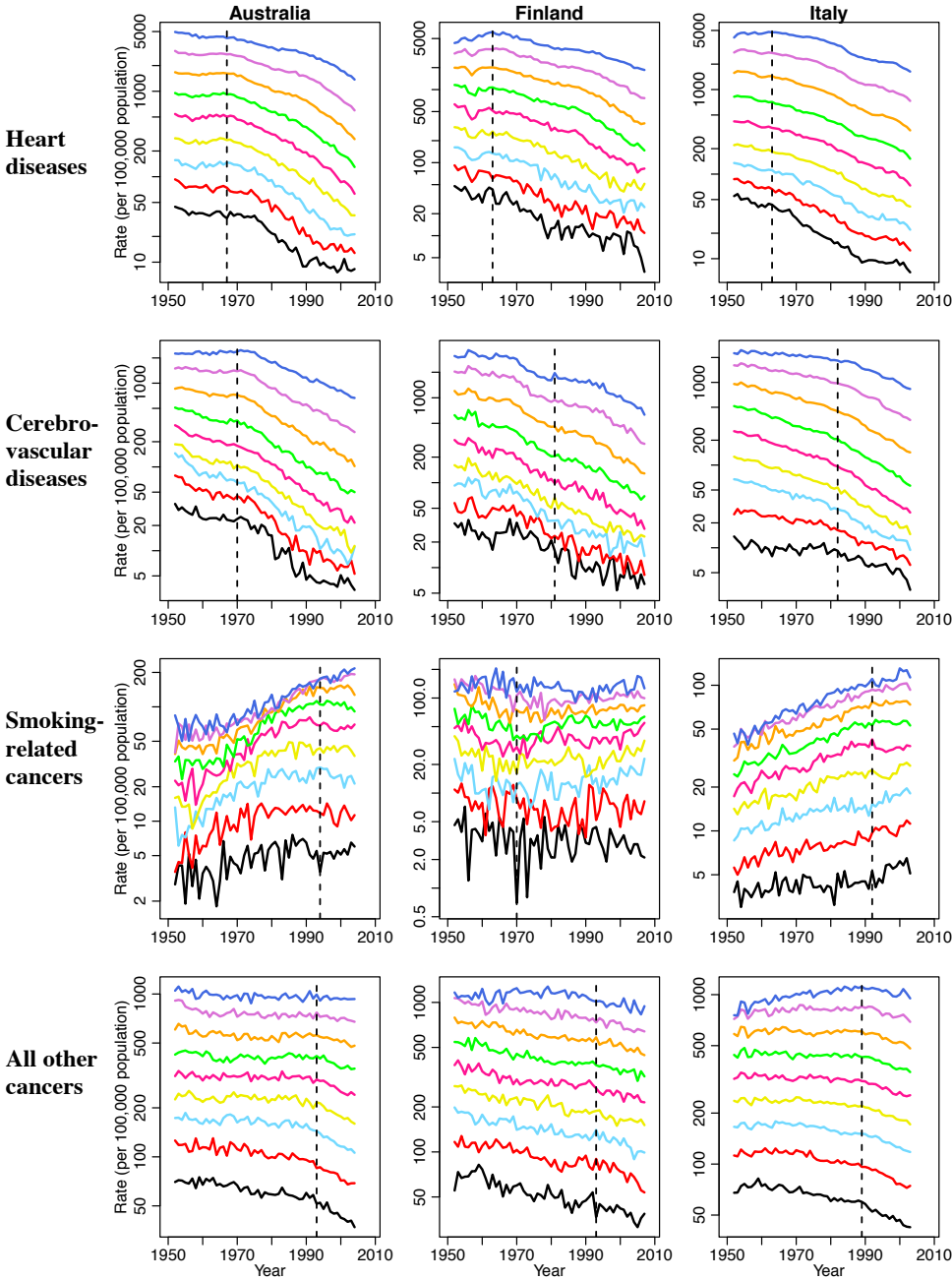
**FIGURE 5A Age-specific death rates for selected causes of death in Australia, Finland, and Italy, males aged 40–44 to 80–84, 1952–2007**



NOTES: The distinctive lines designate the same age group in all 12 graphs. Lines are ordered from the lowest age group (40–44 years) at the bottom to the highest (80–84 years) at the top. The vertical dashed line indicates the year of the dominant turning point in the age-standardized male death rate trend for the given cause of death and country (Table 2A). The smoking-related cancer death rate includes all deaths from malignant neoplasms of lip, oral cavity, pharynx, esophagus, larynx, trachea, bronchus, and lung as the underlying cause.

SOURCE: Authors' calculations based on the HMD (2011) and WHO Mortality Database (2011).

**FIGURE 5B** Age-specific death rates for selected causes of death in Australia, Finland, and Italy, females aged 40–44 to 80–84, 1952–2007



NOTES: The distinctive lines designate the same age group in all 12 graphs. Lines are ordered from the lowest age group (40–44 years) at the bottom to the highest (80–84 years) at the top. The vertical dashed line indicates the year of the dominant turning point in the age-standardized female death rate trend for the given cause of death and country (Table 2B). The smoking-related cancer death rate includes all deaths from malignant neoplasms of lip, oral cavity, pharynx, esophagus, larynx, trachea, bronchus, and lung as the underlying cause.

SOURCE: Authors' calculations based on the HMD (2011) and WHO Mortality Database (2011).

to the best-fitting two-slope regression model (by a criterion of maximum  $R^2$ ). Of the three countries investigated more thoroughly here, the dominant turning point in trends by age groups (for males) took place over the longest period of time in Finland. However, the range covers only 18 years, which corresponds to less than half of what would be expected from pure cohort effects. In Australia and Italy, the discontinuities identified for the various age groups occurred within an even narrower range (roughly five years), thus invalidating the hypothesis that cancer mortality changes around that time were driven predominantly by cohort-based factors. These findings suggest that with respect to the recent improvements in smoking-related cancer mortality, cohort effects have been largely mitigated by powerful period effects. In other words, a combination of period- and cohort-based factors appears to have caused the more recent decline in smoking-related cancer mortality.

For all other cancers, the results are more ambiguous. Mortality trends for this group of diseases show some variations by age but without the mostly regular shift exhibited by smoking-related cancer mortality. In Italy and Australia, for instance, as in several other countries, the apparent dominant turning point in mortality trends for cancers that are not closely related to smoking shifted slightly with advancing age for males and females aged 40–59, but the decline seems to have occurred more systematically around 1990 for persons aged 60 and above (Figures 5A and 5B). Therefore, the contribution of cohort factors to changes in mortality trends is much less certain than for smoking-related cancers.

## Discussion

Our analysis indicates that the accelerated mortality decline of the late 1960s documented for men in the United States was not exceptional. Many other high-income countries also experienced noticeable turning points in trends around the same time. Improvements in cardiovascular disease mortality, which unfolded in a highly similar manner, were the major contributor to this striking change in trend, which occurred for most countries outside Eastern Europe in the years around 1970. A later, more modest turning point in all-cause mortality seems to coincide with a change in cancer mortality trends in the 1980s or the 1990s depending on the country. Our main finding is that these changes in trend affected most age groups (ages 40 and above) simultaneously for heart diseases and cerebrovascular diseases, and with a slight time lag for smoking-related cancers that is much less obvious for all other cancers.

The evidence presented here illustrates the significance of certain period-based changes, which are experienced by multiple age cohorts around the same time. Although we cannot rule out cohort factors as drivers of the more recent reduction in death rates, especially those for smoking-related cancers,

period factors appear to have played the dominant role in the most significant epidemiologic transformation of this era, namely the extraordinary decline in cardiovascular mortality that was initiated in most countries around 1970.

The literature on trends in mortality from cardiovascular disease has identified medical progress as the major cause of the unanticipated longevity increase experienced by many low-mortality countries at the end of the 1960s and thereafter (Julian 1989; Pitt 1989; McGovern et al. 1996). In general, more efficient management of diseases of the circulatory system and their risk factors—including diagnostic methods, pharmacological regulation of blood pressure and cholesterol, and treatment options—led to both delayed onset and improved survival experienced by the population starting around 1970. The resulting reductions in cardiovascular disease morbidity and mortality were sufficiently widespread and rapid for various observers to talk of a “cardiovascular revolution” (Vallin and Meslé 2004).

It appears that changes in individual behavior also played a part in this revolution, in particular with respect to tobacco consumption (Burke et al. 1989; Levi et al. 2002). Smokers have a higher risk of developing cardiovascular disease than both former smokers and non-smokers (Ockene et al. 1990; Anthonisen et al. 2005). The evidence suggests, however, that cardiovascular disease is affected more by current or recent smoking status than by past smoking history. Research suggests that about half of the decline in mortality from diseases of the cardiovascular system in high-income countries is attributable to changes in major risk factors, including smoking, and half to specific treatments (Bots and Grobbee 1996; Capewell et al. 2010; Unal, Critchley, and Capewell 2004). Thus, it is plausible that the anti-smoking campaigns of the late 1960s and 1970s contributed to the period-based decline in cardiovascular disease mortality identified here. The role of behavior in mortality trends from cardiovascular disease also helps to explain sex differences in the timing of mortality change from this category of diseases: although it is likely that men and women benefited simultaneously from the medical innovations of the 1960s and 1970s, the effect of medical progress is confounded by sex differences in tobacco consumption, because women in many of these countries began smoking in large numbers around the time when men started to stop.

By contrast, the risk of smoking-related cancers is determined not so much by current smoking status as by the lifetime history of smoking and its characteristics (i.e., duration and intensity of tobacco consumption). Individuals who have never smoked have a much lower risk of dying from cancers of the lung, pharynx, and esophagus than those who have smoked moderately or who have stopped smoking; those who have stopped smoking, in turn, are at lower risk of dying from such cancers than individuals who have continued smoking throughout their lives (Ockene et al. 1990; Doll et al. 2004; Anthonisen et al. 2005). Thus, for certain cancers, the long-term cumulative

effects of smoking are more clearly attached to specific cohorts as a result of their smoking histories (age at initiation, frequency of smoking, and kinds of tobacco products consumed). Smoking cessation has a smaller, delayed impact on cancer mortality than on mortality from cardiovascular diseases.

As for mortality from all other cancers combined, we found only weak evidence of cohort effects and a strong indication that if any of these have been at play, they must have been combined with period factors. We recognize, however, that the broad disease categories examined here combine a large spectrum of conditions, each with its own set of etiologic factors. Because it is unlikely that all risk factors, prevention strategies, and treatment interventions specific to each of the conditions within a single broad category will change simultaneously, their separate effects on overall trends will tend to be overlooked. This issue is particularly relevant for the disease category that combines all cancers other than those clearly related to smoking, for which aggregate trends may mask the more systematic patterns of mortality change that might have occurred for specific cancers. The data available at present (via the WHO Mortality Database) do not permit a more detailed disaggregation of cancer mortality in a manner that is both consistent over all four revisions of the International Classification of Diseases and comparable across many countries.

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## Notes

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1 Earlier studies (e.g., Derrick 1927; Davidson and Reid 1927) had also highlighted the relevance of cohort influences for adult mortality using a different approach.

2 A similar but weaker pattern was detected by Kermack and colleagues for Scotland (1870–1872 to 1930–1932) and Sweden (1761–1770 to 1924–1926).

3 The Appendix is provided online at [http://www.demog.berkeley.edu/directories/profiles/Ouellette\\_Barbieri\\_Wilmoth\\_PDR\\_2014\\_OnlineAppendix.pdf](http://www.demog.berkeley.edu/directories/profiles/Ouellette_Barbieri_Wilmoth_PDR_2014_OnlineAppendix.pdf).

4 In this article, we use the expressions “diseases of the circulatory system” and “cardiovascular diseases” interchangeably.

5 All of the two-slope regression models that were used to identify the dominant discontinuity years listed in Table 1 provided a better description of the data than the comparable one-slope models (F-tests for nested models resulting in  $p \leq .01$ ). Moreover, these statistical models accounted for more than 90 percent of variability in the data in each case, except for Poland ( $R^2=86$  percent), Slovakia ( $R^2=73$  percent), Bulgaria ( $R^2=62$  percent), and Hungary ( $R^2=62$  percent).

6 We used Fisher’s exact test to determine whether there were nonrandom associations between the trend in mortality before the main turning point (with mortality either “leveling-off,” “decreasing,” or “increasing”) and the timing of the change in trend (with three possible periods: “1968–1969,” “1970–1972,” and “1973–1974”), which resulted in  $p = .833$ .

7 The exceptionally rapid mortality decline recorded in Japan before the mid-1980s is partly attributable to the overlap of two epidemiological transitions: the reduction in mortality from infectious and parasitic diseases and the reduction from cardiovascular diseases (Horiuchi and Wilmoth 1998). In most of the other study countries, these transitions occurred in two clearly separate periods.

8 The other countries (outside Eastern Europe) are Australia, Austria, Ireland, and New Zealand.

9 Results available on request from nadine.ouellette@ined.fr.

10 Nearly all of the two-slope regression models that were used to identify the timing and magnitude of the dominant turning point in cause-specific mortality trends in the various countries provided a better description of the data than the comparable one-slope models (F-tests for nested models resulting in  $p \leq .01$ ). Exceptions are designated by “..” in Tables 2A and 2B and involve only three small

countries with relatively large year-to-year fluctuations, namely Iceland, Luxembourg, and Switzerland. For heart diseases, cerebrovascular diseases, and smoking-related cancers, the two-slope models accounted for more than 90 percent of variability in the data in about 90 percent of cases. For all other cancers, it accounted for more than 80 percent of variability in the data in 70 percent of cases.

11 As indicated in the notes to Tables 2A and 2B, a single dagger next to the year of the turning point indicates that mortality fell less rapidly after the turning point than before it. A double dagger indicates that death rates increased after the turning point while they had been stable or declining before, or increased more rapidly than previously.

12 We used Fisher's exact test to measure the association between the timing of the change in trend (with two possible values: “1980s or earlier” and “1990s or later”) and the magnitude of the change (“high,” “moderate,” or “low”), which resulted in  $p = .023$ .

## References

- Anthonisen, Nicholas R. et al. 2005. “The effects of a smoking cessation intervention on 14.5-year mortality: A randomized clinical trial,” *Annals of Internal Medicine* 142(4): 233–240.
- Barbi, Elisabetta and Carlo G. Camarda. 2011. “Period and cohort effects on elderly mortality: A new relational model for smoothing mortality surfaces,” *Statistica* 71(1): 51–69.
- Barbi, Elisabetta and James W. Vaupel. 2005. “Comment on inflammatory exposure and historical changes in human life-spans,” *Science* 308(5729): 1743.
- Barker, David J. P. 1995. “Fetal origins of coronary heart disease,” *British Medical Journal* 311: 171–174.
- Bengtsson, Tommy and Martin Lindström. 2000. “Childhood misery and disease in later life: The effects on mortality in old age of hazards experienced in early life, southern Sweden, 1760–1894,” *Population Studies* 54(3): 263–277.
- Bots, Michiel L. and Diederick E. Grobbee. 1996. “Decline of coronary heart disease mortality in the Netherlands from 1978 to 1985: Contribution of medical care and changes over time in presence of major cardiovascular risk factors,” *Journal of Cardiovascular Risk* 3(3): 271–276.
- Burke, Gregory L. et al. 1989. “Trends in CHD mortality, morbidity and risk factor levels from 1960 to 1986: The Minnesota Heart Survey,” *International Journal of Epidemiology* 18(3) (Suppl. 1): S73–S81.
- Capewell, Simon et al. 2010. “Cardiovascular risk factor trends and potential for reducing coronary heart disease mortality in the United States of America,” *Bulletin of the World Health Organization* 88(2): 120–130.
- Cohen, Alan, John Tillinghast, and Vladimir Canudas-Romo. 2010. “No consistent effects of prenatal or neonatal exposure to Spanish flu on late-life mortality in 24 developed countries,” *Demographic Research* 22(20): 579–634.

- Crimmins, Eileen M. 1981. "The changing pattern of American mortality decline, 1940–77, and its implications for the future," *Population and Development Review* 7(2): 229–254.
- Davey Smith, George and Diana Kuh. 2001. "Commentary: William Ogilvy Kermack and the childhood origins of adult health and disease," *International Journal of Epidemiology* 30: 696–703.
- Davidson, Andrew R. and A. R. Reid. 1927. "On the calculation of rates of mortality," *Transactions of the Faculty of Actuaries* 11: 183–232.
- Derrick, V. P. A. 1927. "Observations on (1) errors of age in the population statistics of England and Wales, and (2) the changes in mortality indicated by the national records," *Journal of the Institute of Actuaries* 58(2): 117–159.
- Doblhammer, Gabriele. 2004. *The Late Life Legacy of Very Early Life*. Heidelberg: Springer.
- Doll, Richard, Richard Peto, Jillian Boreham, and Isabelle Sutherland. 2004. "Mortality in relation to smoking: 50 years' observations on male British doctors," *British Medical Journal* 328(7455): 1519–1528.
- Doll, Richard, Richard Peto, Keith Wheatley, Richard Gray, and Isabelle Sutherland. 1994. "Mortality in relation to smoking: 40 years' observations on male British doctors," *British Medical Journal* 309: 901–911.
- Elo, Irma T. and Samuel H. Preston. 1992. "Effects of early-life conditions on adult mortality: A review," *Population Index* 58(2): 186–212.
- Finch, Caleb E. and Eileen M. Crimmins. 2004. "Inflammatory exposure and historical changes in human life-spans," *Science* 305(5691): 1736–1739.
- Fisher, Walter D. 1958. "On grouping for maximum homogeneity," *Journal of the American Statistical Association* 53: 789–798.
- Fogel, Robert William. 2004. "Changes in the process of aging during the twentieth century: Findings and procedures of the *Early Indicators* project," *Population and Development Review* 30(Suppl.): 19–47.
- Frost, Wade H. 1939. "The age selection of mortality from tuberculosis in successive decades," *American Journal of Hygiene* 30: 91–96.
- Gagnon, Alain and Ryan Mazan. 2009. "Does exposure to infectious diseases in infancy affect old-age mortality? Evidence from a pre-industrial population," *Social Science & Medicine* 68(9): 1609–1616.
- Gordon, Tavia and Thomas Thom. 1975. "The recent decrease in CHD mortality," *Preventive Medicine* 4(2): 115–125.
- Human Mortality Database (HMD). 2011. University of California, Berkley (USA), and Max Planck Institute for Demographic Research (Germany). «<http://www.mortality.org>». Accessed 15 April 2011.
- Hobcraft, John, Jane Menken, and Samuel H. Preston. 1982. "Age, period, and cohort analysis in demography: A review," *Population Index* 48(1): 4–43.
- Horiuchi, Shiro and John R. Wilmoth. 1998. "Deceleration in the age pattern of mortality at older ages," *Demography* 35(4): 391–412.
- Julian, Desmond. 1989. "Treatment for chronic CHD," *International Journal of Epidemiology* 18(3) (Suppl. 1): S228–S230.
- Kannisto, Väinö, Kaare Christensen, and James W. Vaupel. 1997. "No increased mortality in later life for cohorts born during famine," *American Journal of Epidemiology* 145(11): 987–994.
- Kermack, William O., Anderson G. McKendrick, and Peter L. McKinlay. 1934a. "Death rates in Great Britain and Sweden: Some general regularities and their significance," *Lancet* 226: 698–703.
- . 1934b. "Death rates in Great Britain and Sweden: Expression of specific mortality rates as products of two factors and some consequences thereof," *Journal of Hygiene* 34: 433–457.
- Levi, Fabio, Francesca Lucchini, Eva Negri, and Carlo La Vecchia. 2002. "Trends in mortality from cardiovascular and cerebrovascular diseases in Europe and other areas of the world," *Heart* 88(2): 119–124.

- Luy, Marc. 2004. "Mortality differences between Western and Eastern Germany before and after Reunification: A macro and micro level analysis of developments and responsible factors," *Genus* LX(3-4): 99–141.
- McGovern, Paul G. et al. 1996. "Recent trends in acute coronary heart disease: Mortality, morbidity, medical care, and risk factors," *The New England Journal of Medicine* 334(14): 884–890.
- Miller, Kristen, Robert A. Hummer, Ryan K. Masters, and Brian K. Finch. 2011. "Black/white differences in US adult mortality: An examination of recent period and cohort trends," paper presented at the Annual Meeting of the Population Association of America, Washington DC, 31 March–2 April.
- Muggeo, Vito M. R. 2003. "Estimating regression models with unknown break-points," *Statistics in Medicine*, 22: 3055–3071.
- Murphy, Michael. 2010. "Reexamining the dominance of birth cohort effects on mortality," *Population and Development Review* 36(2): 365–390.
- Myrskylä, Mikko. 2010. "The relative effects of shocks in early- and later-life conditions on mortality," *Population and Development Review* 36(4): 803–829.
- Ockene, Judith K., Lewis H. Kuller, Kenneth H. Svendsen, and Elaine Meilahn. 1990. "The relationship of smoking cessation to coronary heart disease and lung cancer in the Multiple Risk Factor Intervention Trial (MRFIT)," *American Journal of Public Health* 80(8): 954–958.
- Pitt, Bertram. 1989. "Therapy for myocardial infarction: Effect on trends in coronary disease mortality," *International Journal of Epidemiology* 18(3) (Suppl. 1): S223–S227.
- Preston, Samuel H., Nathan Keyfitz, and Robert Schoen. 1972. *Causes of Death: Life Tables for National Populations*. New York: Seminar Press.
- Preston, Samuel H. and Haidong Wang. 2006. "Sex mortality differences in the United States: The role of cohort smoking patterns," *Demography* 43(4): 631–646.
- Preston, Samuel H., Dana A. Gleit, and John R. Wilmoth. 2010. "Contribution of smoking to international differences in life expectancy," in Eileen M. Crimmins, Samuel H. Preston, and Barney Cohen (eds.), *International Differences in Mortality at Older Ages: Dimensions and Sources*. Washington, DC: National Academies Press, pp. 105–131.
- Rogers, Roger G., Robert A. Hummer, Patrick M. Krueger, and Fred C. Pampel. 2005. "Mortality attributable to cigarette smoking in the United States," *Population and Development Review* 31(2): 259–292.
- Ryder, Norman B. 1965. "The cohort as a concept in the study of social change," *American Sociological Review* 30(6): 843–861.
- Slocum, Terry A., Robert B. McMaster, Fritz C. Kessler, and Hugh H. Howard. 2005. *Thematic Cartography and Geographic Visualization*, 2<sup>nd</sup> Edition, Upper Saddle River, NJ: Prentice Hall.
- Spiegelman, Mortimer. 1968. "Mortality in the United States: A review and evaluation of special reports of the National Center for Health Statistics," *Demography* 5(1): 525–533.
- Thun, Michael J. et al. 1997. "Trends in tobacco smoking and mortality from cigarette use in Cancer Prevention Studies I (1959 through 1965) and II (1982 through 1988)," in Donald R. Shopland, David M. Burns, Lawrence Garfinkel, and Jonathan M. Samet (eds.), *Changes in Cigarette-Related Disease Risks and Their Implication for Prevention and Control: Smoking and Tobacco Control*. Bethesda: National Institutes of Health, Monograph 8, pp. 305–382.
- Unal, Belgin, Julia A. Critchley, and Simon Capewell. 2004. "Explaining the decline in coronary heart disease mortality in England and Wales between 1981 and 2000," *Circulation* 109(9): 1101–1107.
- US Department of Health and Human Services. 2004. *The Health Consequences of Smoking: A Report of the Surgeon General*. Atlanta: US Department of Health and Human Services, Centers for Disease Control.
- Vallin, Jacques and France Meslé. 2004. "Convergences and divergences in mortality: A new approach to health transition," *Demographic Research*, Special collection 2: 11–44.
- Vaupel, James W., James R. Carey, and Kaare Christensen. 2003. "It's never too late," *Science* 301(1679): 1679–1681.
- Wilmoth, John R. 1990. "Variation in vital rates by age, period, and cohort," *Sociological Methodology* 20: 295–335.

- . 2006. "Age-period-cohort models in demography," in Graziella Caselli, Jacques Vallin, and Guillaume Wunsch (eds.), *Demography: Analysis and Synthesis, 1*. San Diego: Elsevier, pp. 227–236.
- World Health Organization (WHO). 2011. Detailed data files of the World Mortality Database. «<http://www.who.int/whosis/mort/download/en/index.html>». Accessed 21 April 2011.
- Yang, Yang. 2008. "Trends in US adult chronic disease mortality, 1960–1999: Age, period, and cohort variations," *Demography* 45(2): 387–416.