Visualizing Mortality Dynamics for Causes of Death in the United States

Extended Abstract

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Abstract

Demography is blessed with a wealth of data of relatively high quality. Hence, the challenge for demographers is not to make inferences based on small samples but to make sense of the available data, capturing essential trends and not omitting major characteristics. Mortality surface maps have been used to summarize millions of events with several thousand data points in a single figure. Building on those surfaces, we argue that maps of the rates of mortality improvement provide an even better tool to understand the underlying mortality dynamics. Using multiple cause of death data from the NCHS and exposures from the Human Mortality Database, we show that the slow increase of US life expectancy can be attributed to a mixture of period and cohort effects. Mortality from circulatory diseases improved enormously due to strong period effects. This development is counteracted by cohort effects of malignant neoplasms, in particular lung cancer.

Advantanges of data in demography

The available data give demography a competitive advantage in relation to most other (social) sciences in at least four dimensions: 1) Fertility and mortality, the main parameters, which determine the size and structure of a population, are clearly defined. 2) They are routinely collected on an annual basis in most countries. 3) The data is — at least in developed countries — of relatively high quality. 4) Demographic data contain information about millions of events. In 2010, for instance, there were about four million births and 2.5 million

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deaths in the United States according to the Human Mortality Database (2013).[1] With data dating back to 1933, more than 280 million births and almost 150 million deaths have been recorded in the US.

The challenge

Hence, the challenge for demographers is not to make inferences based on small samples but to make sense of the available data, capturing essential trends and not omitting major characteristics. Due to their construction, summary indices such as the crude birth rate, the TFR, the crude death rate, life expectancy, ..., necessarily cannot take all important aspects into account. As all demographers know: The same crude death rates can be measured in two countries with relatively large differences in their respective mortality regimes.

Visualization on the Lexis Surface

Visualizing data as a Lexis surface map, i.e. rates or counts by year and age, is the most suitable approach to depict this wealth of data in our opinion.

> To look at 20,000 numbers and draw out their meaning is a major research enterprise in itself. Yet on the methods used in this book all that information is contained in a single contour map.
>
> Nathan Keyfitz in his foreword to Vaupel et al. (1985), referring to Swedish mortality data.

Information Contained in Lexis Map

One loses still some information: In a single year in the US, more than two million death counts are compressed into 100 values. Despite this reduction by several orders of magnitude, there are still thousands of data points to display. Nevertheless, the amount of single data entries[2] is larger than the median or even the maximum value measured by Edward Tufte in statistical graphics in a variety of publications (Tufte, 2001, 2003). Still, when printed on a book page with standard margins[3] the density of about 230 distinct data points per square inch is well above the lower limit of the human eye (Tufte, 2001).

History of Mortality Surface Maps

To our knowledge, Delaporte in 1938 was the first person to introduce mortality surfaces (p. 202).[4] In the early 1980s, Arthur and Vaupel (1984) provided a mathematical foundation for the demographic analysis on the Lexis surface, followed by articles and papers in the following years (e.g., Caselli et al., 1985; Vaupel et al., 1985, 1987, 1985). Before the availability of R and comparable computer software, which facilitate the creation of surface maps, Kirill Andreev's software LEXIS enabled researchers for the first time to create surface maps without computer programming skills (e.g., Andreev, 2002; Vaupel et al., 1997).

[1] Together with more than 16 billion person-years lived if age-specific death rates are estimated.
[2] For the United States: 78 years by 100 age = 7800 data points.
[3] The printable area is approximately 7.5in $\times$ 4.5in $=$ 33.75 square inch.
[4] Nowadays, the display would be called a "wireframe".

Our suggestion

Based on the previous work of mortality surfaces and modern approaches to data smoothing, we argue that surface maps of rates of mortality improvement allow us to understand mortality dynamics even better. Surfaces of rates of mortality improvement simply depict the time derivative of age-specific death rates. Kannisto et al. (1994) introduced average rates of improvement. While our approach is similar, we differ from Kannisto et al. (1994) in three aspects: First, we use a continuous time version of Kannisto's equation.[5] Second, we use single ages instead of large age-groups. Third, instead of reporting numerical values we (obviously) plot those values.

Mortality Surface Maps in General

The left panel of Figure 1 on page 7 shows the distribution of death counts by single year (1950–2010) and age (0–100) for US women. In the middle panel of Figure 1 those death counts have been divided by their respective exposures to obtain death rates. Assuming a Poisson distribution (Brillinger, 1986), these death rates have been smoothed in the right panel with the *P*-spline approach of Eilers and Marx (1996) using the package "MortalitySmooth" by Camarda (2009; 2012). The same colors correspond to the same levels of mortality, accentuated by three contour lines.

Surface Maps of Rates of Mortality Improvement

While the colors and the upward trends of the contour lines already suggest that mortality is decreasing, there are debates about how mortality has changed. Were period or cohort effects more instrumental? Plotting the rates of mortality improvement (see Figure 2, page 8) allows some answers without the standard identification problem of APC analysis. White areas denotes age-specific death rates, which remained constant over time. Increasingly darker shades of grey indicate worsening survival. Blue and green colors shows slight and moderate mortality improvements, respectively. Rapid mortality declines are illustrated by red, orange, and yellow. The aspect ratio of the figure has been chosen in a way that one calendar is the same length as one age year. Consequently, cohort effects correspond to patterns on the 45 degree line. Mortality for women in the US seems to have a multitude of influences. In the 1970s, remarkable improvements in mortality were observed at virtually ages, i.e. a strong period effect. The minor increases in life expectancy between 1980 and 2000 was influenced by some cohort patterns in grey.

Maps for Causes of Death

We decided to investigate this pattern deeper by analyzing causes of death. Data on causes of death from the National Center for Health Statistics are available from 1959 until 2010 and can be downloaded from the National Bureau of Economic Research (National

[5] The basis for Kannisto's estimates of the rate of change ρ is $m(x, t+\delta) = m(x,t) \times (1+\rho)^{\delta}$; we use $m(x, t+\delta) = m(x,t)e^{\rho\delta}$ with $\delta = 1$.

Center for Health Statistics, 2013). The coding of causes, in particular across the ICD revisions 8, 9, and 10 was based on the schemes published in Janssen et al. (2004) and Meslé and Vallin (2006). The largest number of deaths are attributed to circulatory diseases. Our surface maps of rates of mortality improvement for this category are shown in Figure 3 (p. 9) for women and in Figure 4 (p. 10) for men. One thing appears to be obvious: If circulatory diseases had been the major driving force of mortality in the United States, there would have not been any stagnation. Strong period effects in the 1970s and since 2000 are clearly visible. It can be debated whether we can see a cohort effect from 1980 until 2000 or a period effect slightly distorted by a cohort effect at ages 30 to 50.
Another advantage is also illustrated by both figures: Problems in the raw data or in the reconstruction become easily visible as indicated by the vertical line in 1979/1980 and slightly less in 1967/1968.
The largest single cause, ischaemic heart disease (Figures 5 and 6 on pages 11–12), appears to be the main determinant for the development of all circulatory diseases.

Clear cohort patterns can be observed for malignant neoplasms as shown in Figures 7 (p. 13) and 8 (p. 14) for women and men, respectively. It has been argued that cohort smoking histories are a major determinant for life expectancy changes and that the slow increase in life expectancy among women in the US but also in Denmark is/was a consequence of the high smoking prevalence of females in those countries (e.g., Crimmins et al., 2010, 2011; Jacobsen et al., 2002; Juel, 2000; Preston and Wang, 2006; Wang and Preston, 2009). This perspective is strikingly supported when plotting rates of mortality improvement for lung cancer, the cause of death most severely affected by smoking, in Figures 9 (p. 15) and 10 (p. 16). One can see the same pattern as for all cancers combined; the severity is considerably stronger, though.

Obesity is besides smoking another lifestyle factor cited to have had a dampening influence on life expectancy in the US (e.g., Crimmins et al., 2011). The cause of death, which might have a close link to obesity is diabetes. The corresponding rates of mortality improvement for women and men are illustrated in Figures 11 (p. 17) and 12 (p. 18). While a strong period effect had a strong negative influence from the mid-1980s until the end of the 1990s, the green, red, and even yellow colors at the end of our observation period suggest that the situation might improve again.

In the next steps we will analyze even more causes of death, for instance, selected cancer, respiratory diseases such as pneumonia or asthma, and other causes to obtain a more complete understanding of US mortality dynamics since the 1960s.

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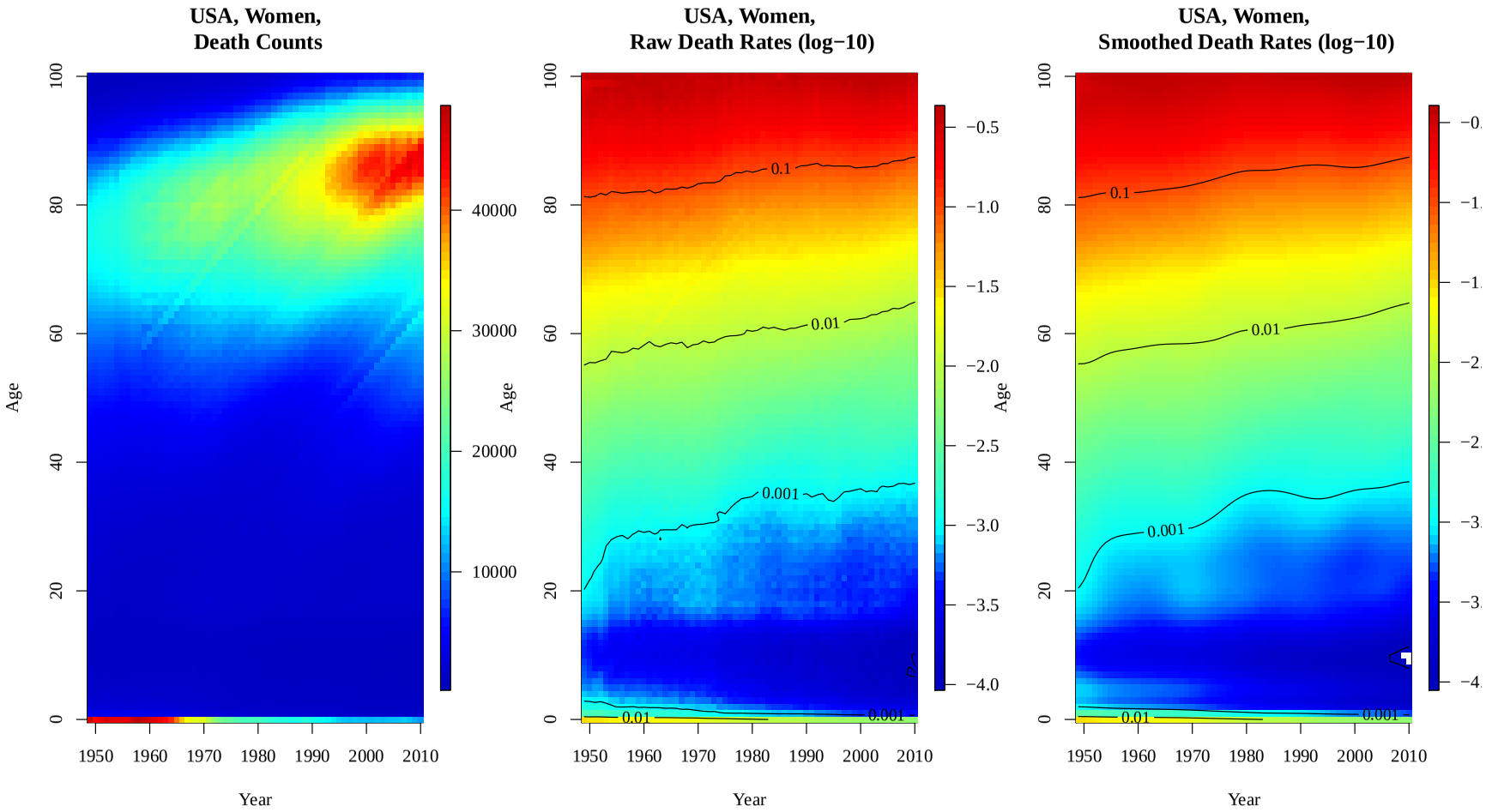

Figure 1: Counts, Raw Rates and Smoothed Rates for US Women by Single Year And Age. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013).

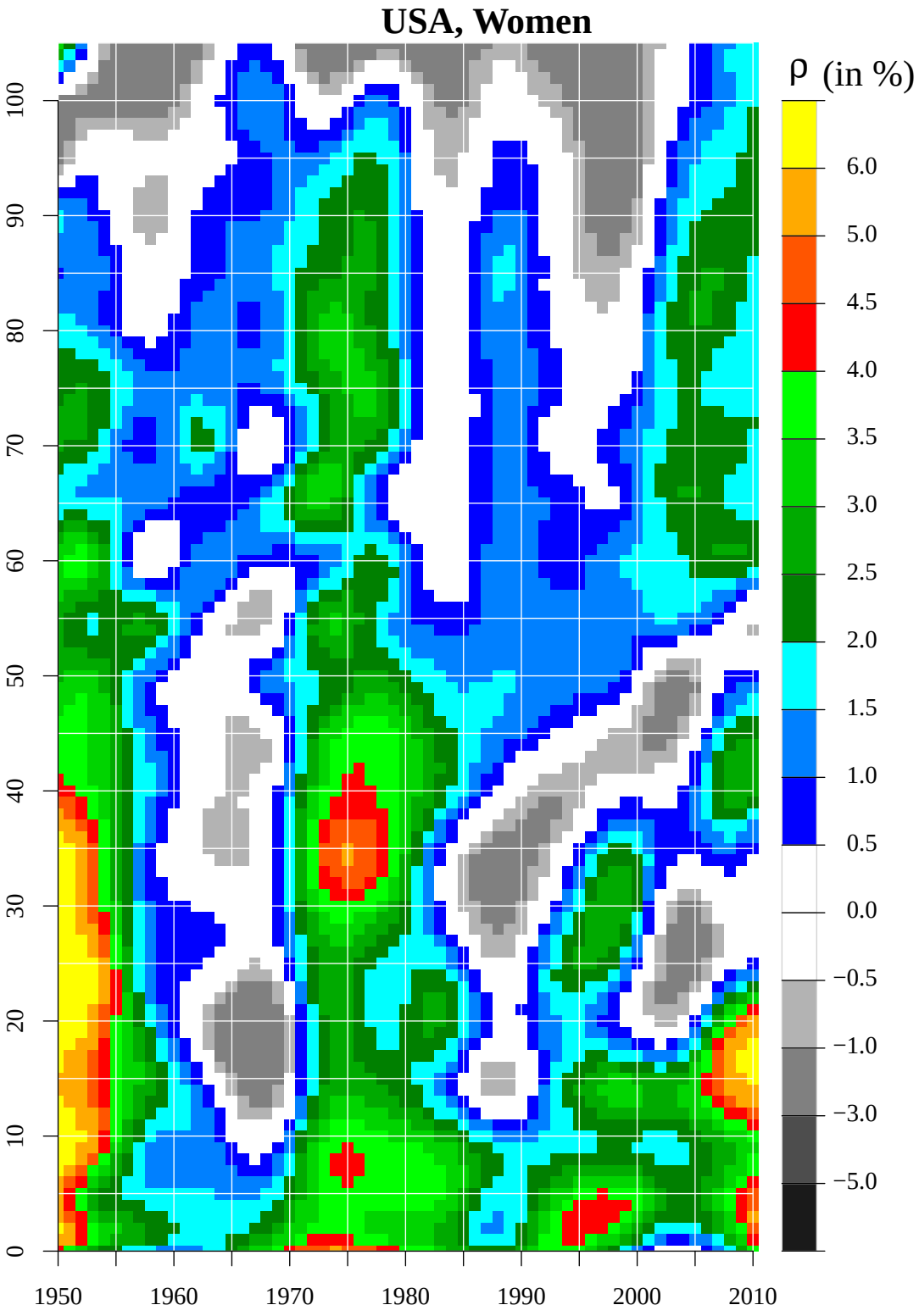

Figure 2: Rates of Mortality Improvement for US Women. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013).

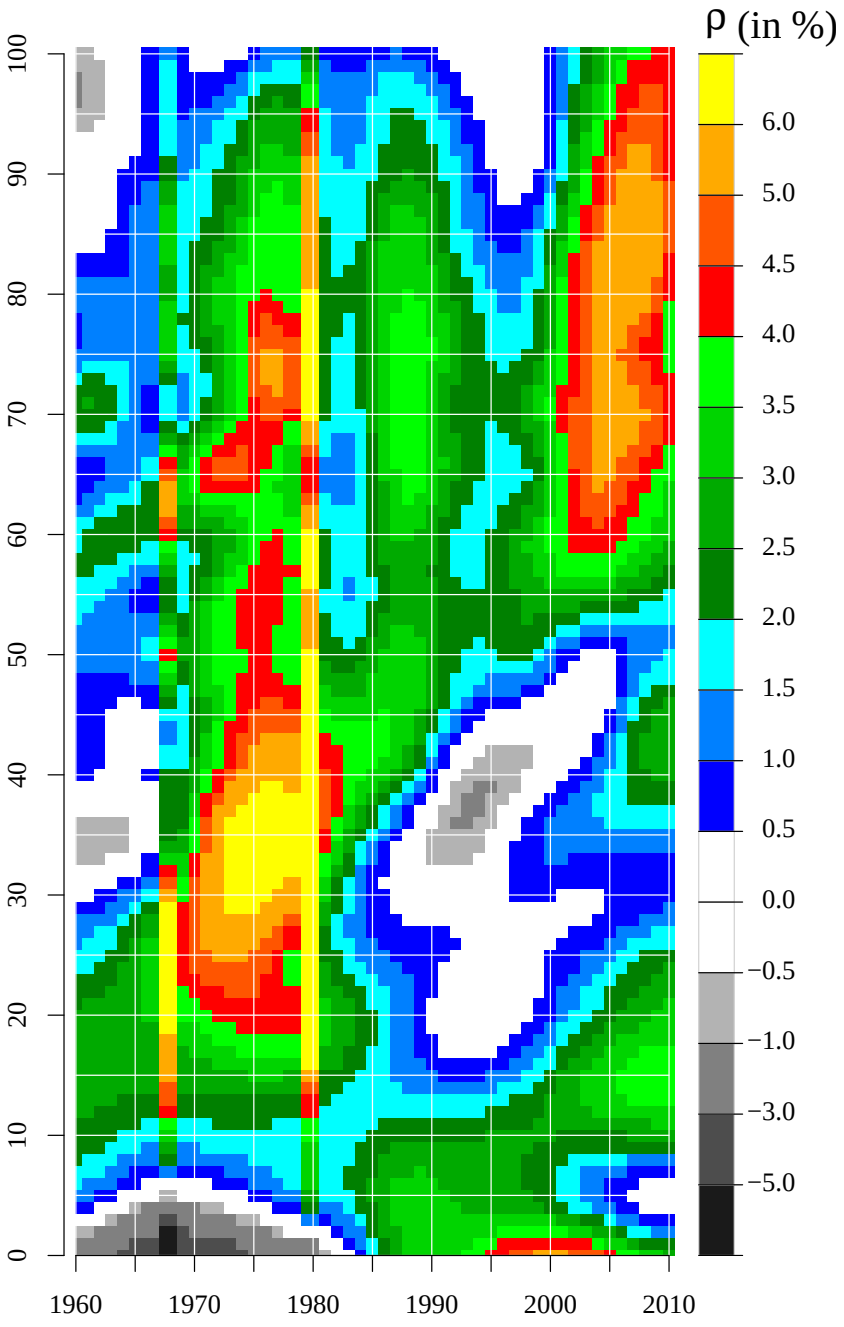

Figure 3: All Circulatory Diseases, Rates of Mortality Improvement for US Women. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

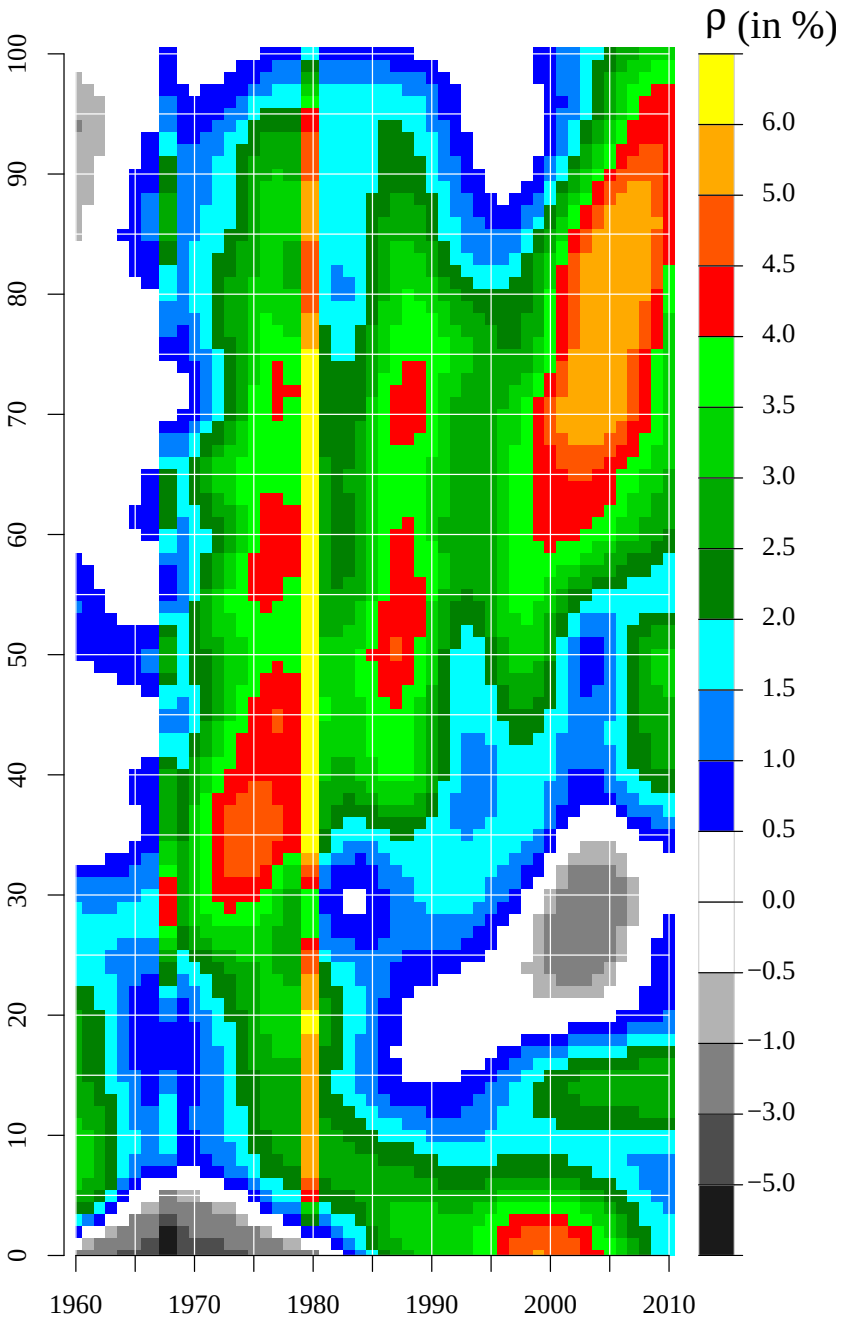

Figure 4: All Circulatory Diseases, Rates of Mortality Improvement for US Men. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

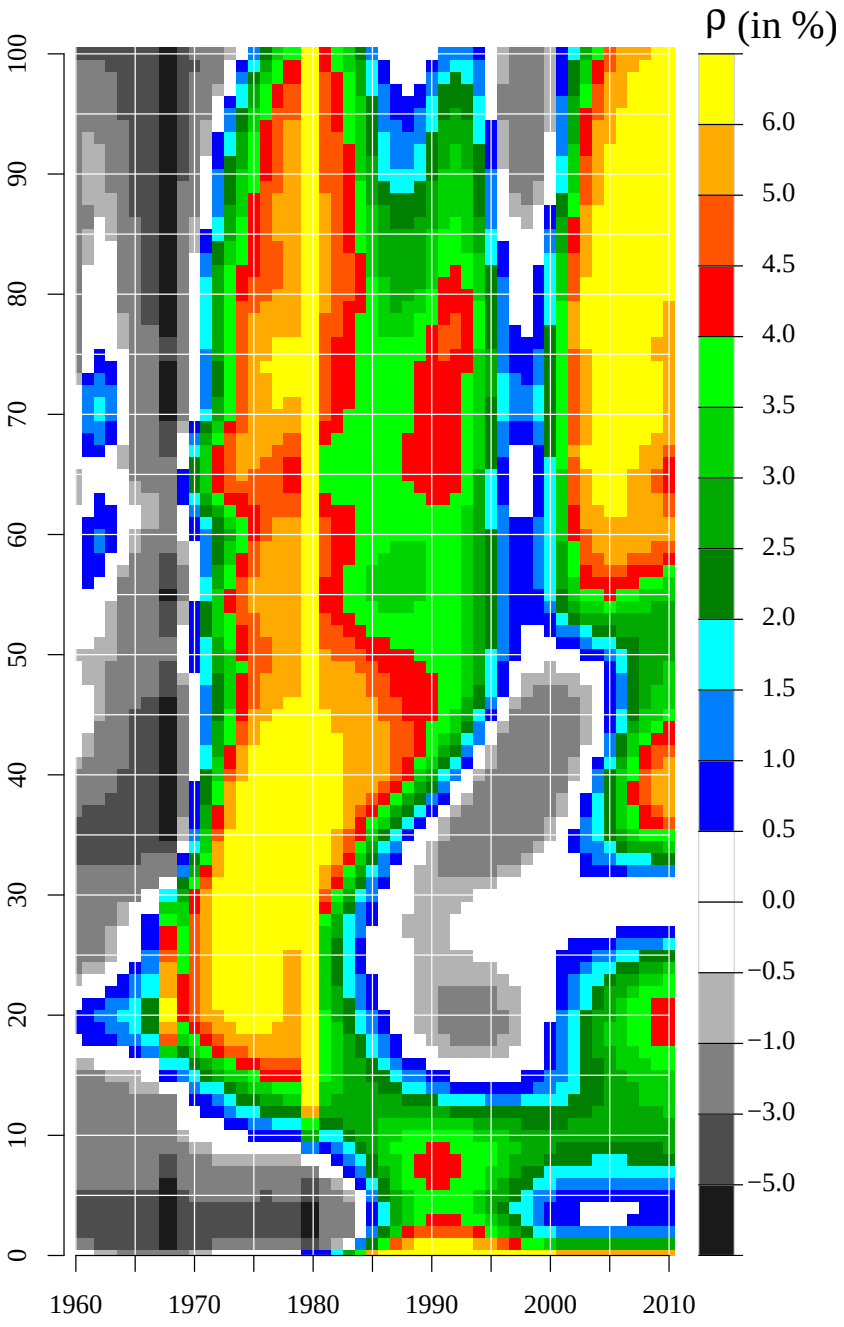

Figure 5: Ischaemic Heart Disease, Rates of Mortality Improvement for US Women. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

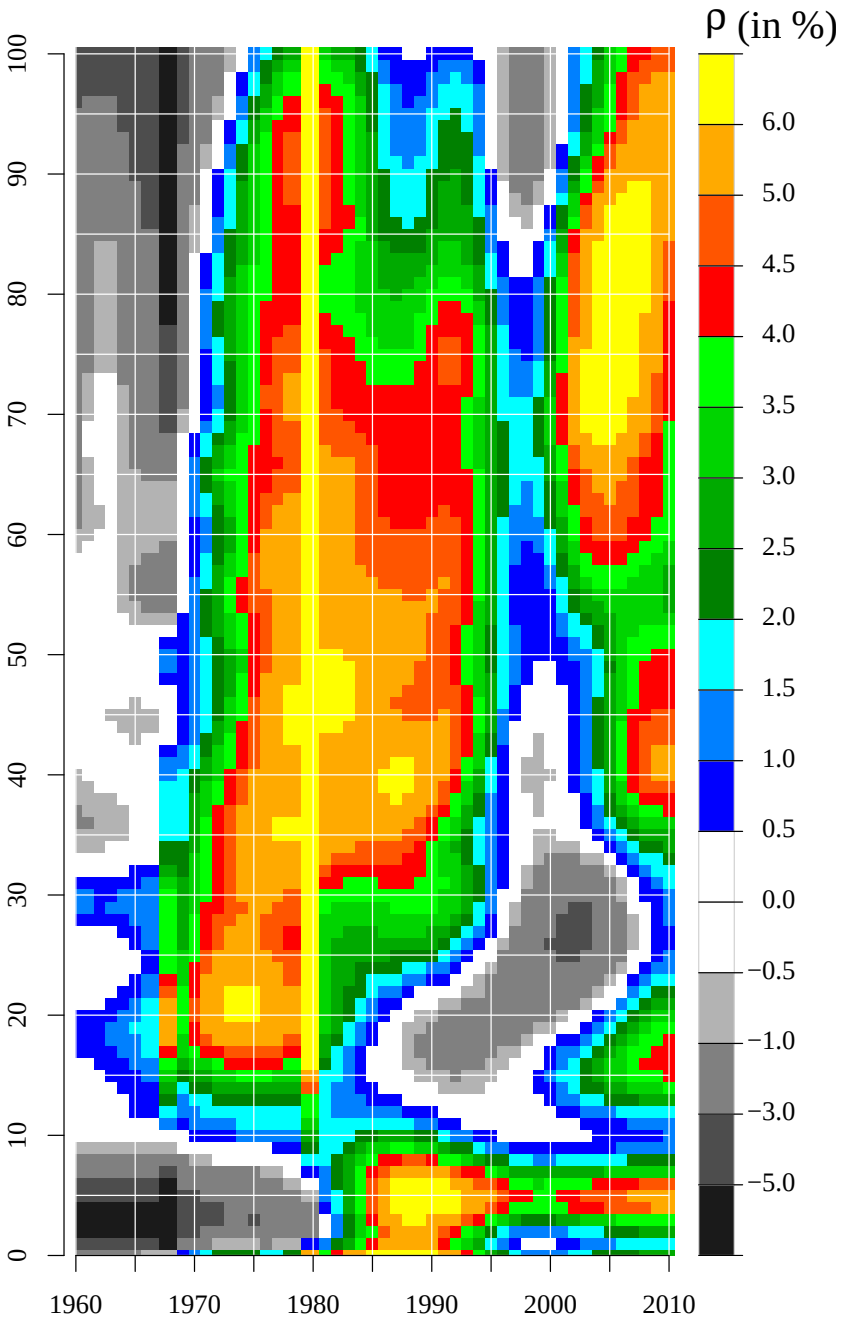

Figure 6: Ischaemic Heart Disease, Rates of Mortality Improvement for US Men. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

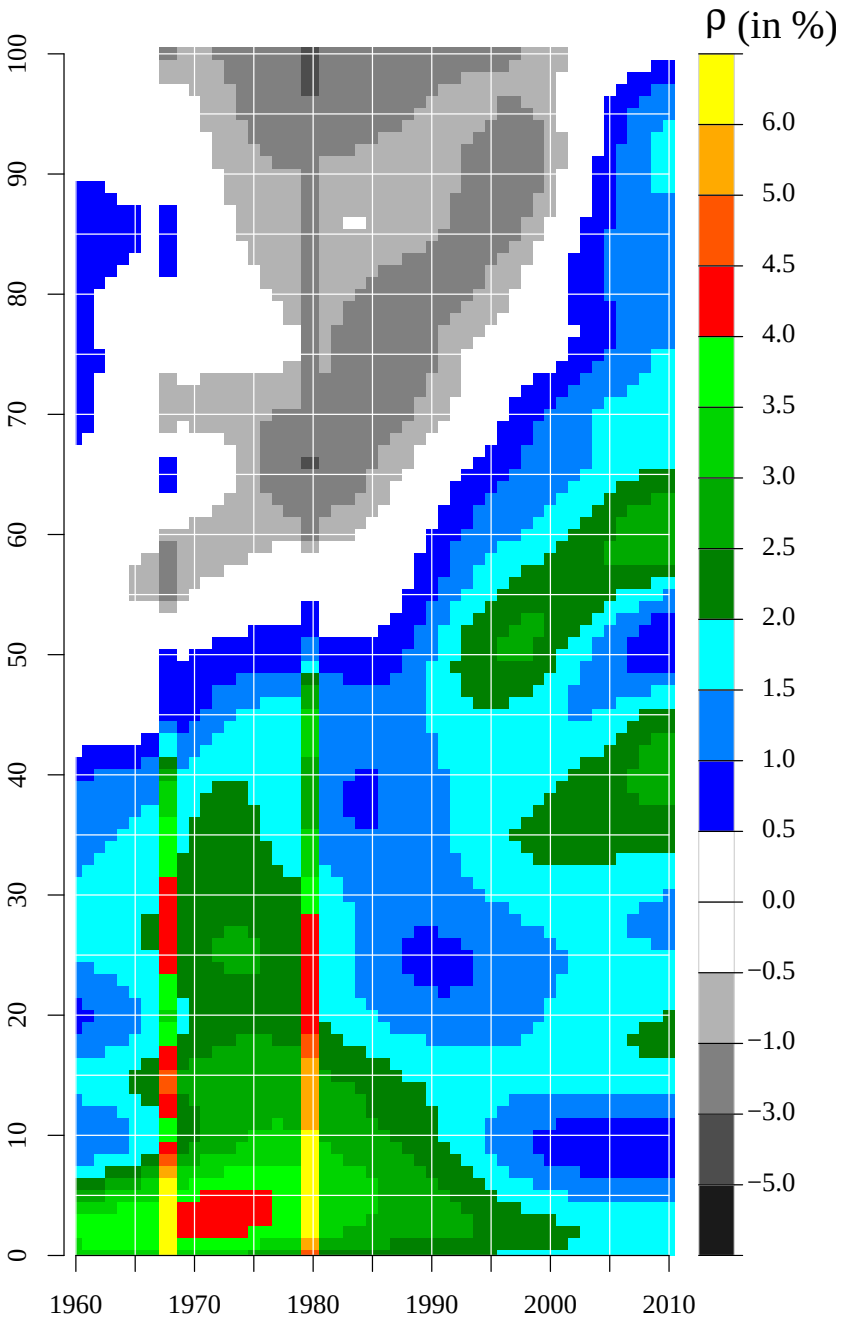

Figure 7: All Malignant Neoplasms (Cancer), Rates of Mortality Improvement for US Women. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

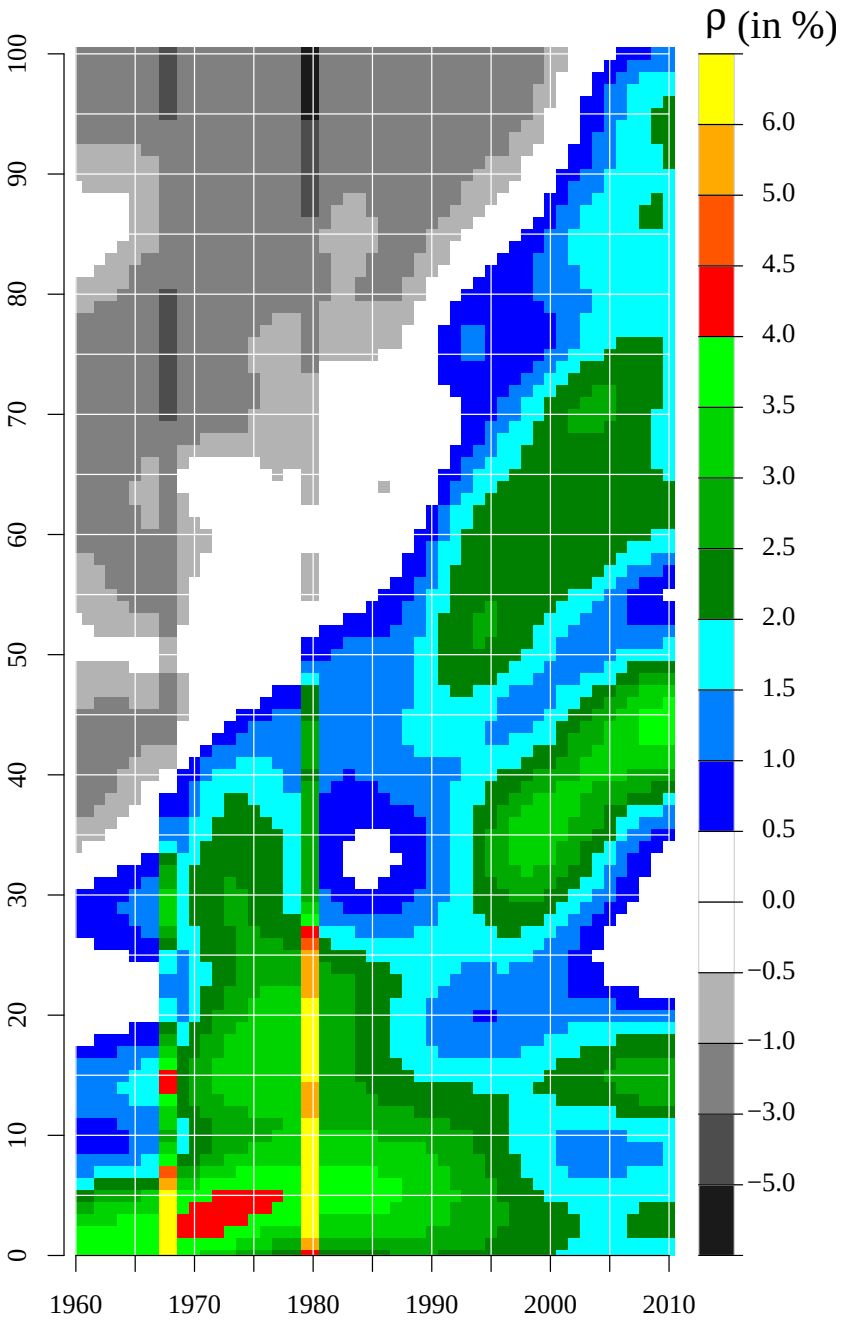

Figure 8: All Malignant Neoplasms (Cancer), Rates of Mortality Improvement for US Men. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

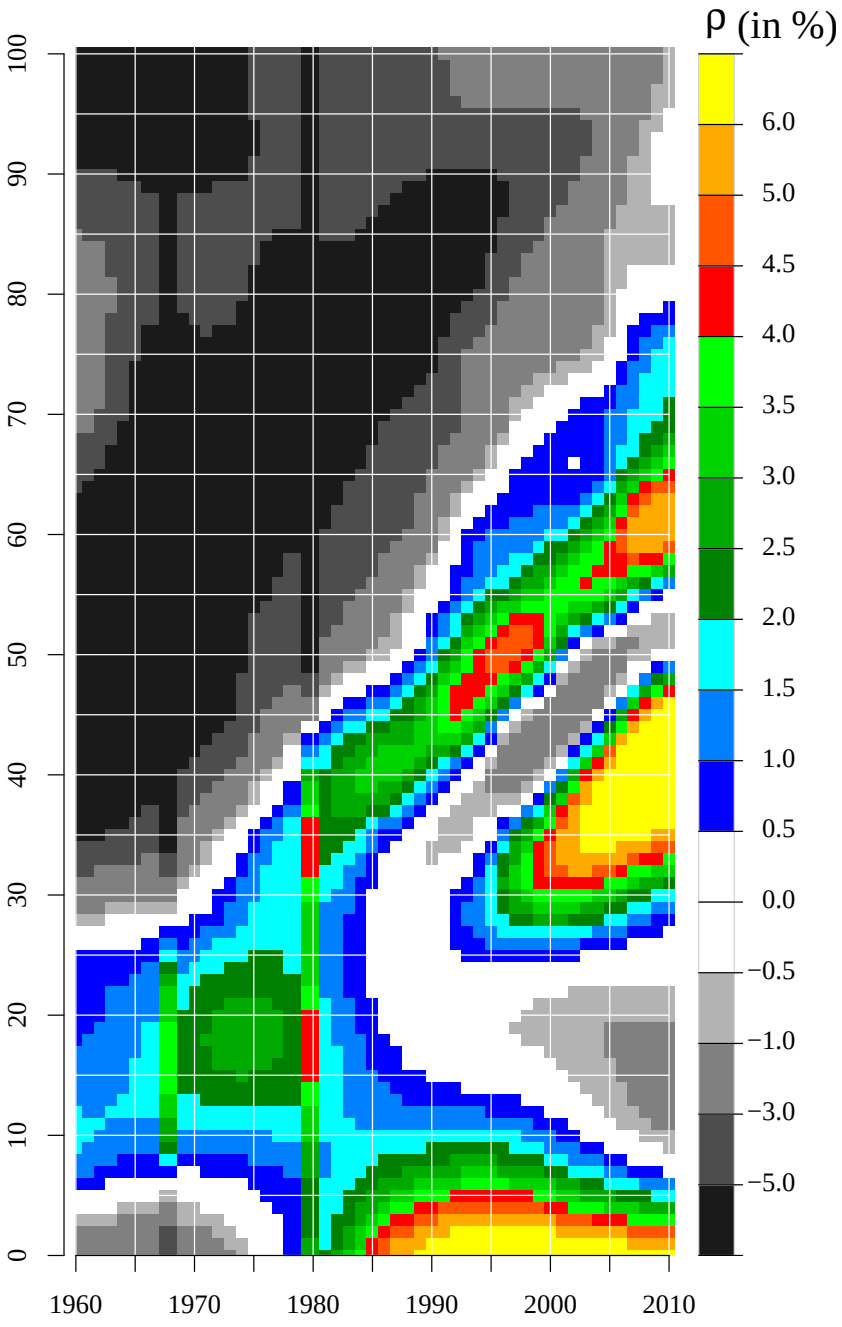

Figure 9: All Malignant Neoplasms (Cancer), Rates of Mortality Improvement for US Women. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

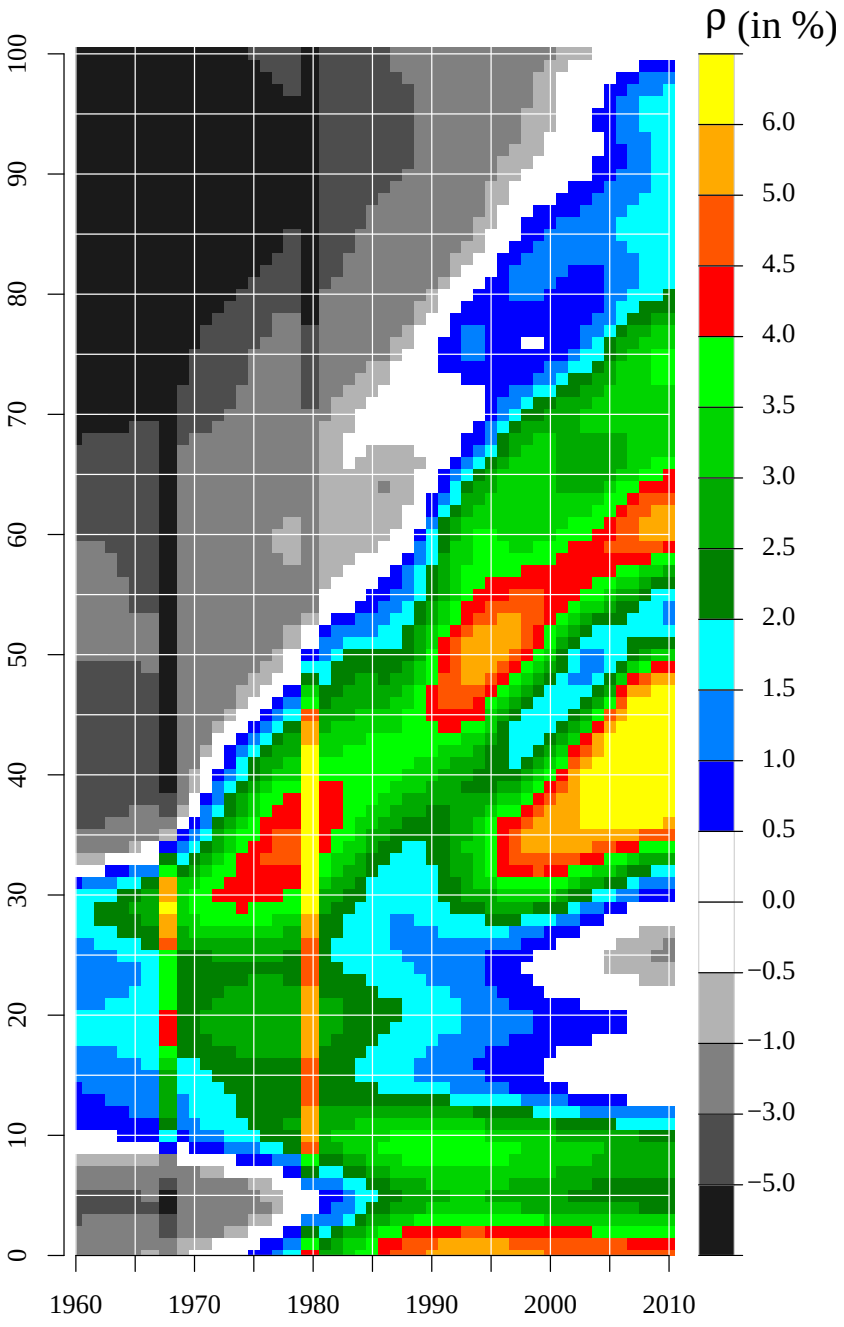

Figure 10: All Malignant Neoplasms (Cancer), Rates of Mortality Improvement for US Men. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

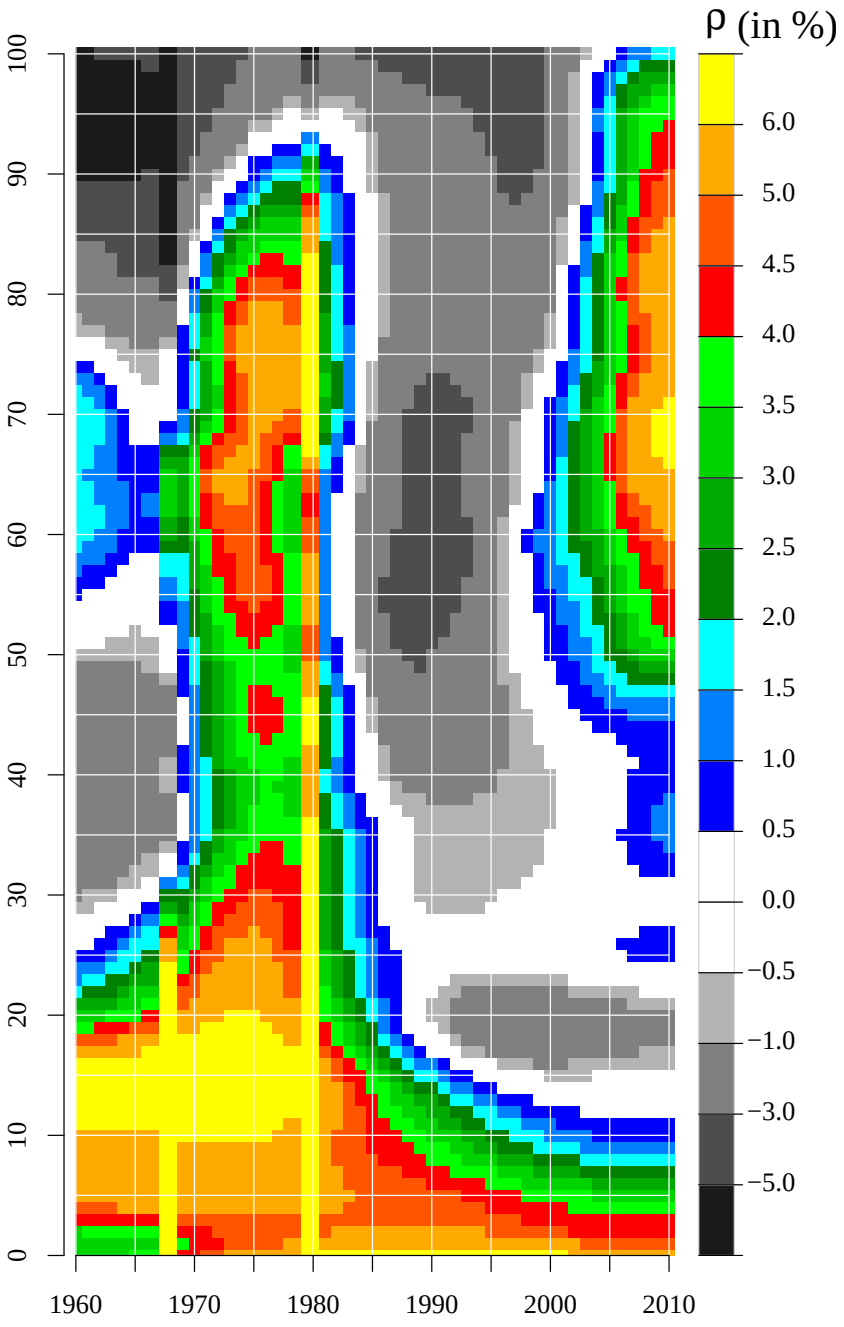

Figure 11: All Malignant Neoplasms (Cancer), Rates of Mortality Improvement for US Women. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).

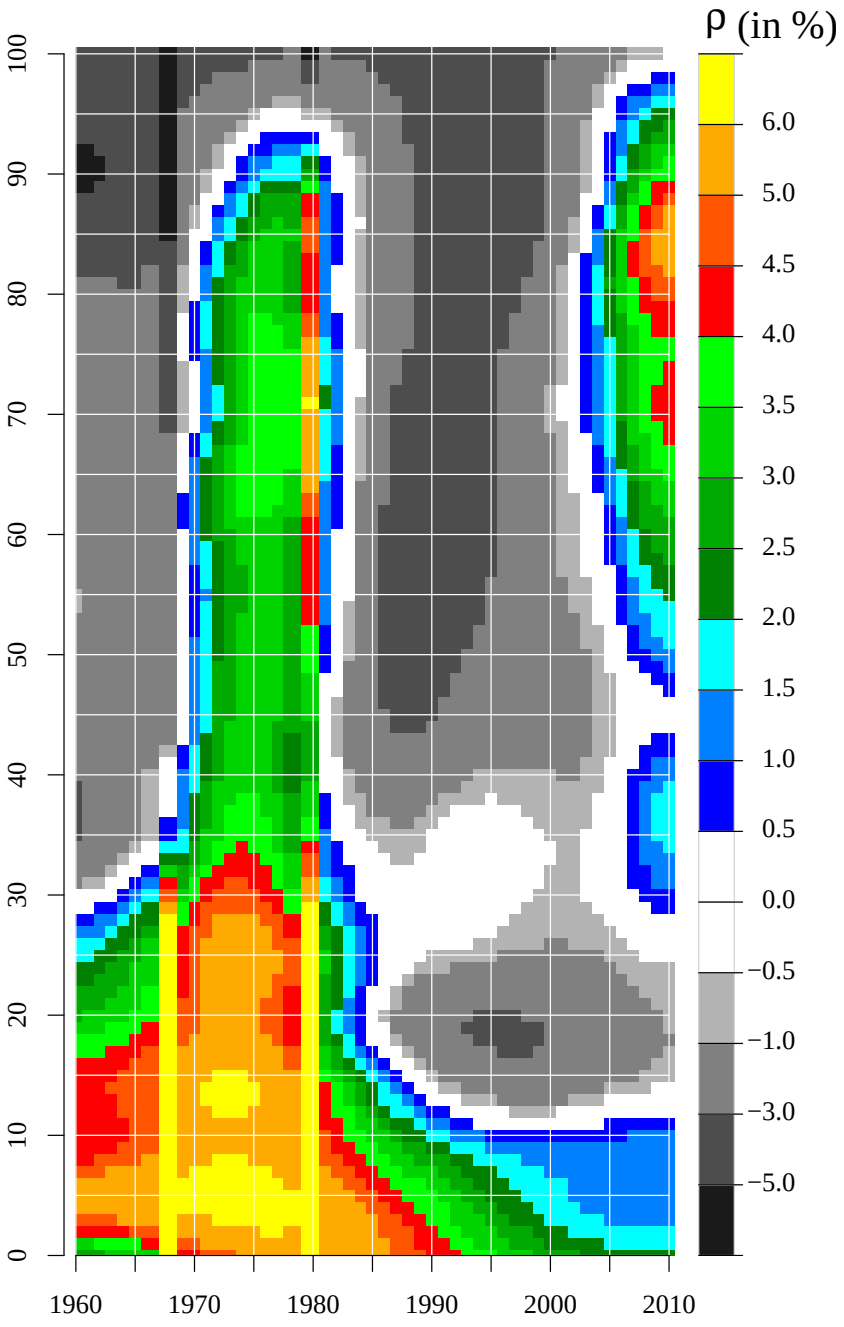

Figure 12: All Malignant Neoplasms (Cancer), Rates of Mortality Improvement for US Men. Source: Illustration of the Authors Based on Data from the Human Mortality Database (2013) and NCHS's Multiple Cause of Death Data (2013).