Comparing the Efficiency of Mortality Changes between Countries: An Evaluation of Past and Forecast Levels in Advanced Economies.

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Abstract

The impact of an age-specific mortality change on life expectancy depends both on its quantity, and its "efficiency" - whether it occurs in an age-group that matters. Since 1840, some countries have stayed close to the advancing linear frontier for life expectancy. This implies that they have efficiently shifted the focus of mortality change from the young, through adults, to the elderly. This paper decomposes annual changes in life expectancy at birth for advanced economies into two components: quantity, and efficiency as defined for a social planner. In the past 50 years, France, Japan and Switzerland have been efficient, suggesting a positive association between the quantity and efficiency of mortality change. The United States has made both smaller and less efficient changes. Efficiency is ignored by forecasting methods. Applying the decomposition to a European Union set of mortality projections reveals an assumption of almost total collapse of efficiency for all countries by 2050.

1 Introduction.

When interpreting the modern rise in life expectancy, historical demographers employ descriptions that imply "targeting" or "efficiency". In the nineteenth century, it is argued that the biggest improvements would come from saving the lives of infants and children and this is what was achieved. Later, the focus turned to the deaths of young adults and, finally, in the modern era we are concerned with saving the lives of the elderly. Is it merely a coincidence that progress was achieved at ages where it had the most impact? Such a question does not seem to have been subject to any formal analysis. Neither do we have an understanding of how it was achieved beyond simple appeals to the idea of public health measures, epidemiology and medical science as deliberate interventions. Several authors [see for example 4] have proposed a "planing off" mechanism where resources are shifted by society or the economy to meet present problems. However, an interpretation of economic forces as benign agents against mortality is rejected by Easterlin [1], who emphasised the need for continuing public intervention.

Governments are concerned with another kind of efficiency - how effectively are health investments translated into health outcomes. This paper attempts to define a demographic measure for the efficiency of mortality changes; to discover which countries can be regarded as efficient; and to speculate as to whether that efficiency will continue in the future.

These questions matter because the social and monetary values of the investments and outcomes are enormous. Figure 1 shows OECD estimates of the investment side: the percentage of GDP spent on health. The US percentage

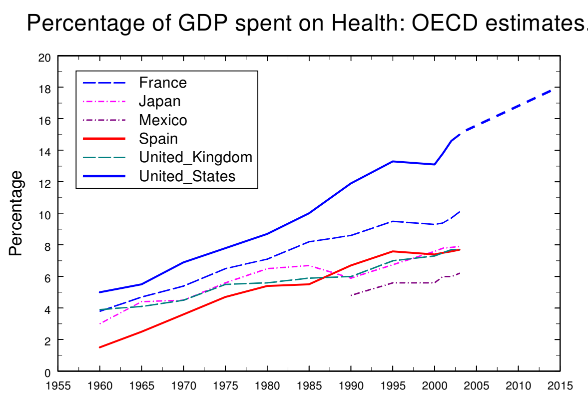


Figure 1:

on health has risen from 5% in 1960, to 15% today, and is projected to rise to 18% by 2015. If other countries follow the US lead, we could see a century in which advanced economies are dominated by their health sectors.

On the outcome side, conventional national economic accounting does not value extension of total lifetime and healthy lifetime, but some estimates are available. For Britain, Crafts has estimated that the rise in life expectancy between 1950 and 2000 was worth about 50% on top of the rapid rise in real incomes as conventionally measured over the same period. This estimate does not include the values attached to the associated falls in morbidity and the variance of lifetimes.

One strand of the debate on health provision asks if too much is being spent. In many countries the political will to spend increasing proportions of public money on health investment seems to be lacking. However, because of the high values that individuals place on health and survival, some economists believe that advanced economies are currently under-spending by as much as 20-25% of GDP.

A second strand asks if current spending is efficiently allocated, but the answers seem to concentrate on the meso- and micro-scales, discussing forms of hospital funding, drug provision, disease-specific interventions, etc.. There seems to have been no attempt to utilize the macro-scale approach to international comparisons afforded by mathematical demography.

To bring such tools into play, this paper imagines how a social planner might view mortality change. Her simplest objective would be to choose age-specific health investments that maximized period life-expectancy at birth in a population, discounted in a period perspective, and subject to a budget constraint. This view contrasts with the individual's concern to maximize, over a cohort perspective, a stream of discounted utility of which healthy living and longer life are just two components.

To make progress with the demography of the social planning scenario, we assume that the weighted average annual change in mortality rates across ages is set by the budget and that the planner can influence mortality rates at will. To simplify the discussion, we make the huge assumptions that age-specific mortality rates are responsive to the investment at that age, and that the elasticity of their response is age-independent. This reduces the planner's problem to one of deciding how to optimize a portfolio of health interventions on the basis of age alone.

2 An Indicator of Demographic Efficiency.

Demographers are familiar with the answers to the questions "What age would you choose if: a) you could save one life, and b) you could change one mortality rate". For b) one should choose an age where there is both a significant number of deaths and period of remaining life expectancy. While the latter answer is technically correct, a social planner should assume that changes at only one age would be subject to rapidly diminishing returns to investment.

A search of the mathematical demography literature for equations that could be interpreted as measuring efficiency led to the equations below, taken from

Vaupel and Canudas Romo [5].

$$\rho(a,t) = -\acute{\mu}(a,t) \tag{4}$$

$$\bar{\rho}(t) = \int_0^{\omega} \rho(a,t) f(a,t) da \tag{6}$$

$$\begin{aligned} \dot{e}^0(0,t) &= \bar{\rho}(t) e^{\dagger}(t) + Cov_f(\rho, e^0) && (12) \\ &= \int_0^{\omega} \mu(a,t)\rho(a,t) l(a,t) e^0(a,t) da \\ &= \int_0^{\omega} \rho(a,t) e^0(a,t) f(a,t) da && (15) \end{aligned}$$

ρ is the rate of progress in reducing death rates where the acute accent over the force of mortality μ denotes the relative derivative or intensity with respect to t. $\bar{\rho}$ is the weighted average improvement in mortality, where the weights are the density of deaths $f(a)$. $\dot{e}^0(0,t)$ is the time derivative of life expectancy at birth. $e^{\dagger}$ is the weighted average number of life years lost as the result of a death.

Vaupel and Canudas Romo wrote:

> The decomposition in Eqn. (12) expresses the change in life expectancy at birth as the sum of two terms. The first term is the product of the average rate of mortality improvement and the average number of life years lost. This term captures the general effect of a reduction in death rates and in this article will be called the "level-1 change." Note that $\bar{\rho}$ can be interpreted as the proportion of deaths averted (or lives saved), and $e^{\dagger}$ can be interpreted as the average number of life-years gained per life saved.
>
> The second term, the covariance between rates of mortality improvement and remaining life expectancies, increases or decreases the general effect, depending on whether the covariance is positive or negative. If $\rho(a,t)$ is constant at all ages, then the covariance is zero. Hence, the covariance captures the effect of heterogeneity in $\rho(a,t)$ at different ages. The covariance term will be called the "level-2 change" in this article.

An optimized age portfolio can be defined with reference to Eqn. (12). It exactly decomposes the time-derivative of life-expectancy into two components. The first can be interpreted as a "quantity" measure. The second term, the weighted covariance between mortality change and remaining life-expectancy, can be thought of as a measure of efficiency or "quality". This equation tells us that a social-planner can increase life-expectancy through the quantity of mortality improvement in the first term, but also by choosing to invest in ages x that have large values of both d_x and e_x, so that the covariance term is maximised. In modern populations aligning the peaks of m_x, d_x and e_x is impossible because high values of d_x are generally associated with low values of e_x, but there is still an optimum distribution. The analysis shows that it is still worthwhile investing in reducing infant rates, but the bulk of the investment should follow the shape of the d_x density although shifted towards younger ages since the e_x function declines approximately linearly with age.

The same equation can also be used if other measures of the value of a remaining life year are employed. Future income could be incorporated as "income-years", or the quality of life may be considered. In both cases it is likely that the "value" measure decreases with age, so we can expect a further leftward shift of the "efficiency" peak towards younger ages.

3 A Simple Model of Efficient Change.

To consider the effect of alternative strategies, we take the position of Japan in 1955.[1] The short time scale in which Japan rose to the top of the world demographic rankings ought to provide insights into efficiency. The red symbols in Figure 2 mark observed female life expectancy. The larger red square shows

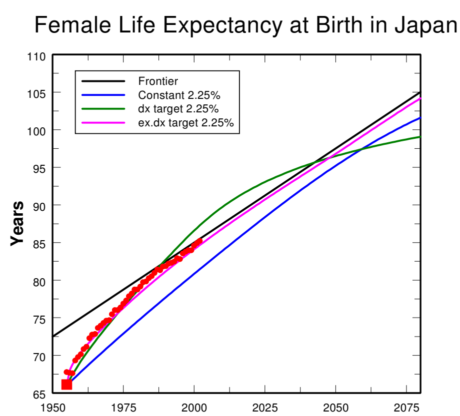


Figure 2:

the starting position in 1955. The black line extrapolates the frontier for life-expectancy identified by Oeppen and Vaupel [3]. Average annual improvement

[1] All the demographic data used in this paper were downloaded from the Human Mortality Database.[2]

is of the order of 2.25%. Suppose that a social planner had a budget that allowed her to change mortality rates by this amount and she chose to alter all rates by a constant factor regardless of age, effectively following a proportional hazard model of change. If this were implemented annually, Japanese female life expectancy would have followed the trajectory of the blue line. The quotation from [5] above informs us that the covariance term in Eqn. (12) will be zero. We can see that actual progress was more efficient, indicating that there was a tendency for age-specific change to be efficient rather than neutral.

A more intelligent planner might decide to concentrate effort at ages where there were more deaths. Making the same annual total quantity of change, but distributing it according to the pattern of the d_x function of the life table in each year would have resulted in the green line. The early years show a pattern of progress that is close to what Japan actually achieved, and observed change is overtaken by 2000. However, we can see that the early gains are not sustained. An informal analysis of the results suggests that the life table rectangularises, so that targeting the d_x function starts to result in smaller and smaller returns in remaining life expectancy.

The final strategy to be considered follows the insights of the Vaupel - Canudas Romo paper. An intelligent social planner informed by demography would target the pattern of mortality reduction towards the age-specific distribution of the product $e_x.d_x$. The outcome of this strategy, updated annually as the life table changes, is shown by the magenta line. Rapid gains in the early years are followed by constant linear improvement. This indicates that continuous progress can be achieved under a constant total proportion of deaths averted if mortality is targeted efficiently.

Although the simple model of efficient change is quite a good match to the observed life expectancy, a summary measure of mortality improvement, an examination of the sequences of the observed and model life-tables tells a more complicated story. The observed life tables for females in Japan suggest that the improvements for teenagers and young adults were too "big" in the early years and that today Japan is making changes at the highest ages that are too large to be "efficient". Of course, the latter would generally be interpreted as good news for the future.

4 International Comparisons.

To illustrate this concept of efficiency in a wider context, Figure 3 shows the components of Eqn. (15) for Spanish females. The colours in the figure match the underlined components in the equation. Mortality change is calculated over two decadal life tables from $1980 - 2000$. Spain was in "catch-up" mode from 1945 to 1980, but had settled into the conventional level of European progress by about 1980. The match between the red and blue lines is reasonably good after the mid-twenties, but is not good at younger ages. In "efficiency" terms, there was too little progress at age zero and too much for children and teenagers.

France, as shown in Figure 4, is one of the most "efficient" countries in

Europe. The excellent match at adult ages between mortality change and a demographer's definition of the "target" pattern can also be seen in Switzerland and Japan.

Spanish and French improvements in survival have been very good in comparison with some other European countries. The same graph, but for Netherlands females, is shown in Figure 5. Most European countries share the same tendency towards large changes at younger ages, but the small quantity of improvement at older ages in the Netherlands is exacerbated by an inability to concentrate the change into those ages where it would have most impact.

The same problems from the perspective of a social planner can be seen for the United States in Figure 6. There is almost no association between mortality change and its "target" distribution. Could it be that the peak around age 50 reflects a process that is economically, rather than socially, targeted?

5 Efficiency in the Future.

The concept of demographic efficiency as a moving target is clearly not an explicit function of the usual methods of mortality forecasting, except that such a process might be embodied in past performance. To examine what a forecast could imply for efficiency, we have taken a suite of forecasts provided by a group of distinguished demographers for 18 European countries over the years

$$\dot{e}^0(0,t) = \int_0^{\omega} \underline{\rho(a,t)}\,\underline{e^0(a,t) f(a,t)}\,da$$

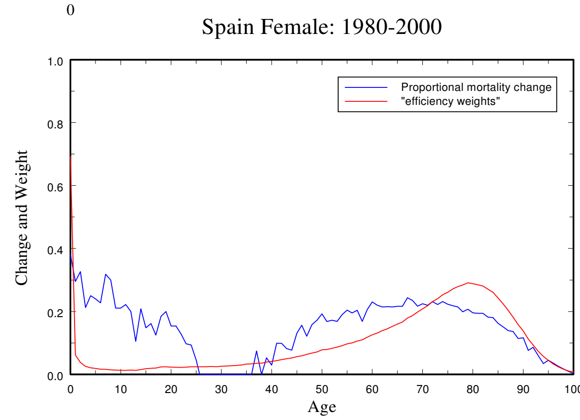


Figure 3:

$$\dot{e}^0(0,t) = \int_0^\omega \rho(a,t)e^0(a,t)f(a,t)da$$

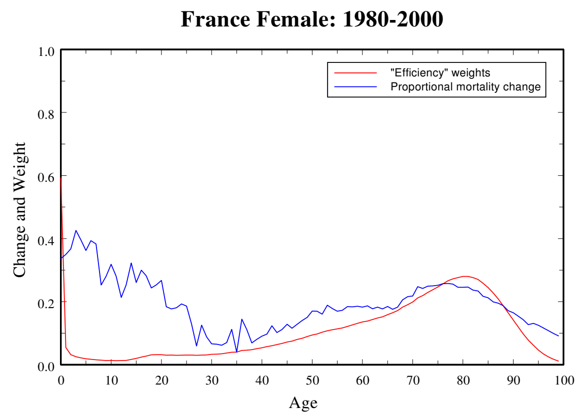


Figure 4:

$$\dot{e}^0(0,t) = \int_0^\omega \rho(a,t)e^0(a,t)f(a,t)da$$

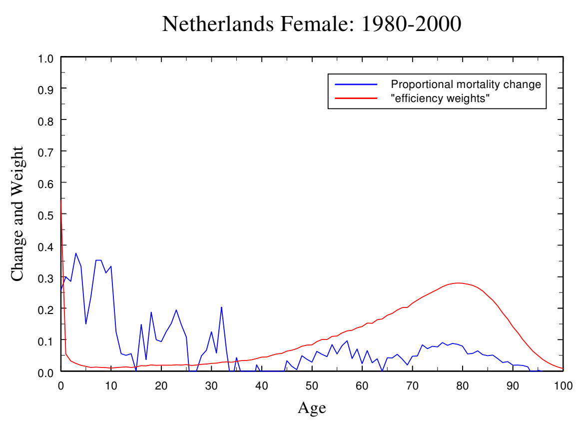


Figure 5:

2004-2050[2]. Figure 7 shows the results for French females. The results should be treated with caution because we are using the forecast to tell us what the efficiency "target" should be, but we do not expect the forecasting method itself to be concerned with "efficiency".[3] Subject to this limitation, the results suggest that by the end of the forecast period, efficiency considerations require mortality changes to peak for 90 year-olds, but the pattern of forecast mortality changes is almost independent of age - effectively close to a proportional-hazard assumption since the blue line is near to horizontal. This may be the most neutral view of the future efficiency of mortality change, but it has never been observed in the historical record. If on the other hand efficiency is maintained at historic levels, life expectancy must exceed these forecasts.

6 Discussion.

The approach taken in this presentation is extremely stylised. It assumes that cohort effects are too small to be worth considering and, more importantly, that all period effects are instantaneous. While it is plausible that a social planner should take a period perspective over the total population, to assume

[2]Available on the Web at http://www.stat.fi/tup/euupe/

[3]Obviously, we would prefer to use an independent, efficient forecast as the benchmark red line.

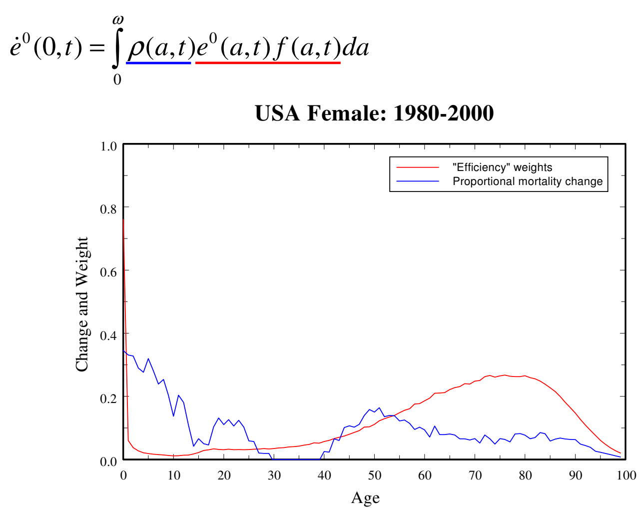


Figure 6:

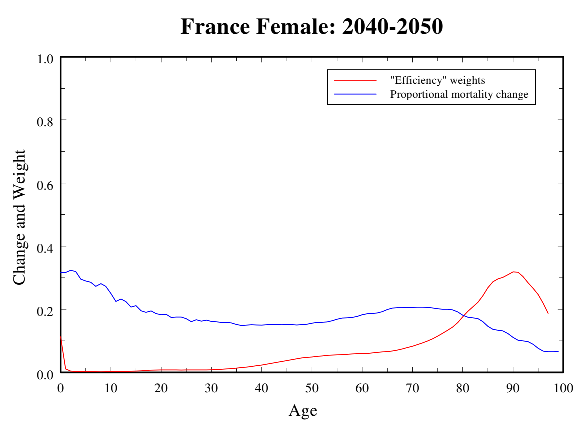
that "investment" at one age leads to mortality improvement at that age in the same period is very dangerous.

The analysis suggests that Japan, France, and Switzerland are among the most demographically efficient, and the approach was motivated by limiting decision-making to a social planner. Thus it may seem paradoxical that these countries are often characterised as offering a high degree of patient choice in health care demand. Is the combination of supply-side social planning and demand-side consumerism the most efficient system?

Is it a coincidence that a simple dynamic model of demographic efficiency leads to straight-line improvements in life expectancy of the sort described by Oeppen and Vaupel, and by White [3, 6]?

The Introduction highlighted the importance of the health sector as a share of GDP in advanced economies. The question of how countries are going to pay for health care in an aging population is always raised. Figure 8 redraws the classic Preston graph of the relationship between GDP *per capita* and life expectancy at birth, although limiting the analysis to 18 advanced economies in Western Europe. Panels are shown for c1950, c2000 and 2049 - the latter from the same source as the previous section. The second half of the 20^{th} century saw a great deal of advance and convergence in the economies and demographies of these countries. Life expectancy for women rose by about 10-15 years but, when expressed in constant dollars, only five countries moved beyond the range of National Income shown in 1950. In other words, most of the countries achieved

$$\dot{e}^0(0,t) = \int_0^{\omega} \underline{\rho(a,t)}\,\underline{e^0(a,t) f(a,t)}\,da$$



Forecast derived from http://www.stat.fi/tup/euupe/

Figure 7:

this improvement in life expectancy within the levels of wealth that could be envisaged as normal in 1950. As Preston suggested, highly developed countries proceed more by advances in health technology than by increases in wealth. The top panel suggests how the picture might look in 2049 with economic growth of 0%. We might hope that this rate is too low, but even at higher rates most of these European countries would still lie within the levels of National Income *per capita* that we observe today.

7 Conclusion.

Posing the question of whether countries exhibit demographic efficiency is not likely to lead to a definitive answer. The purpose of trying to answer this question is to improve our understanding of the past processes of mortality change and to improve our methods of forecasting how they might proceed in the future. These preliminary results suggest support for the "planing off" hypothesis - the best countries seem to be concentrating improvement at ages where it matters, and there seems to be a positive association between quantity and quality. Japan, France and Switzerland seem to be among the most "efficient". The issue of whether such efficiency might be continued in the future is not explicitly considered in current forecasting methods.

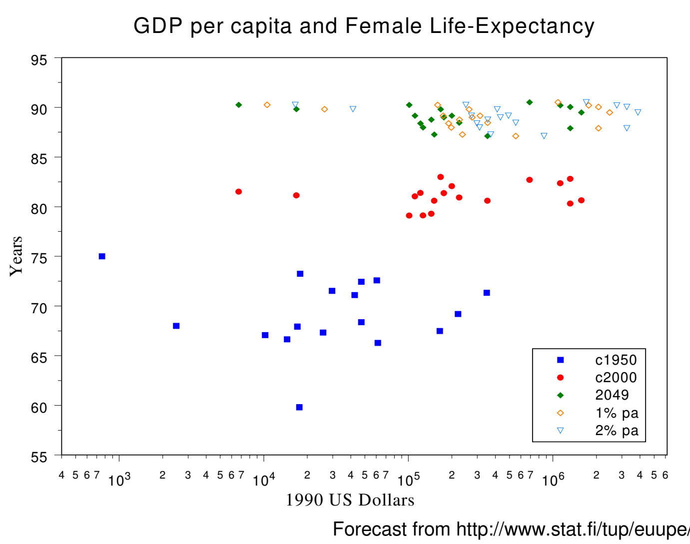


Figure 8:

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