Lifesaving and a new ticket to life: A reappraisal of the resuscitation approach

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Abstract

J. W. Vaupel and Yashin 1987b and J. W. Vaupel and Yashin 1987a developed a demographic model of lifesaving on which the concept of force of mortality μ_x is coupled with the notion of lifesaving $_x$. Their construct allows for assessing the formal relationships between survivorship, density distribution of deaths and life expectancy between two different regimes. In a context of mortality improvement, the new force of mortality can be seen as a decomposition of the old mortality regime μ_x plus a force of lifesaving $_x$. At each age, a proportion δ of individuals who would have died are now resuscitated and given another chance or another ticket to life Wachter n.d. The process can be mathematically described by a factorial reminiscent of the Poisson distribution, resulting in a revivorship function that estimates the probability that an individual will be given n chances (will be resuscitated) i times by age x. We use this relationship to estimate: 1. how many times deaths were averted for Swedish and French females that were born between 1751-1926; 2. the number of life years lived in each resuscitation state; and 3. and decompose life expectancy differentials into gains in τ_i life years at each averted death state. This approach can provide valuable insights into how the lifesaving process unfolds, including its effect on life expectancy and on tempo effects.

Keywords: Resuscitation, Life Expectancy, Second-chance models, Mortality improvement

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1. Rationale

The demographic model of lifesaving developed by

J. W. Vaupel **and** Yashin 1987a combines the concept of force of mortality μ_x with the notion of lifesaving λ_x, wherein mortality improvement can be conceived as both a reduction on the force of mortality μ_x or as an increase in the force of lifesaving λ_x. Hence, progress in mortality can be reviewed through the link between the old and new mortality regimes:

$$\mu_x^* = \mu_x - \lambda_x \tag{1}$$

Where μ_x^* is the new mortality regime and μ_x the old one.

2. Data and Methods

This lifesaving force λ_x can lead to many lives being saved once, more than once or none at all. The effect of saving lives on life expectancy depends on both the number of deaths at various ages and on the number of additional years of life a resuscitated person might have. The number of times deaths were averted in order to achieve a given mortality regime can be described through the "revivorship" function, defined as:

$$l_x^* = l_x + l_i x + l_2 x + ... \tag{2}$$

And that the chances of repeated resuscitation are:

$$l_i x = l_x \Lambda x^i / i!, i = 0, 1, 2, ... \tag{3}$$

Where

$$\Lambda(x) = \int_0^x \lambda(t) dt \tag{4}$$

With

$$\Lambda(x) = \ln(l^*(x)/l(x)) \tag{5}$$

Further, it is possible to establish the relationship between survival under the new and old regimes through:

$$l_{(x)}^* = l_{(x)} + l_x \Lambda_{(x)} + [l_{(x)} \Lambda_{(x)}^2]/2 + ... + [l_{(x)} \Lambda_{(x)}^i]/i! \tag{6}$$

From which we can decompose the value of life expectancy

$$\tau_i = \int_0^{\omega} l_i(x)dx = \int_0^{\omega} l_{(x)}\Lambda^i_{(x)}dx/i!. \tag{7}$$

With

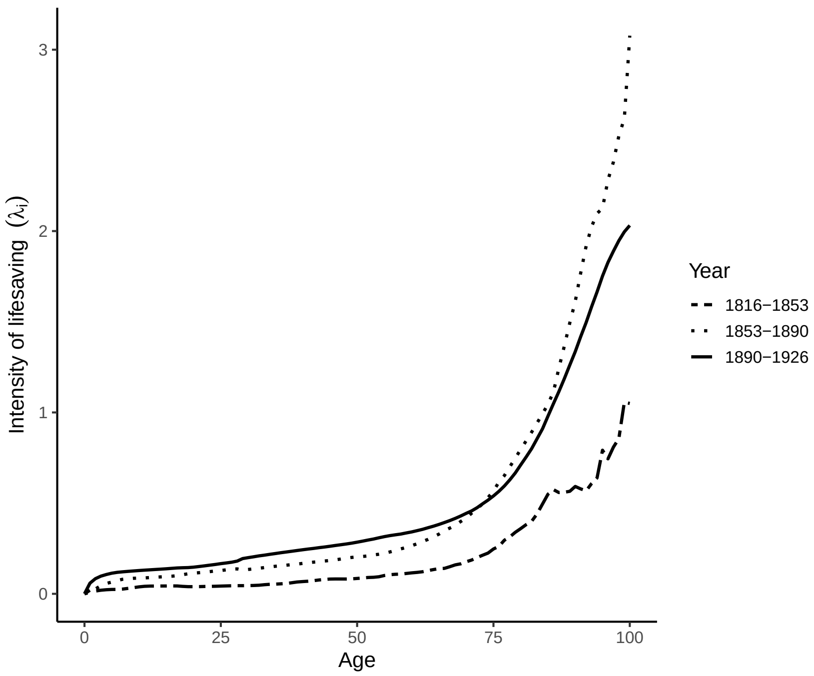
$$\Lambda(x) = \ln(l^*(x)/l(x)) \tag{8}$$

Using this set of relationships and the Human Mortality Database (HMD) birth cohort data from 1751-1926 for French and Swedish women, we show that despite saving lives once is the main contributor to mortality progress, the number of years of life expected to live in more than one resuscitation states increases, as well as the relative contribution of granting people new "life tickets" more than once.

3. Results

For French women the intensity of lifesaving λ_x concentrates towards older ages, particularly at ages 75+. The intensity of lifesaving is also lower at younger ages when comparing mortality progress between 1816-1853 and 1853-1890 relative to the 1890-1926 birth cohorts. However, when comparing the two most recent birth cohorts (1890-1926), the intensity of lifesaving is lower than the previous 1853-1890 cohort comparison at ages 75+.

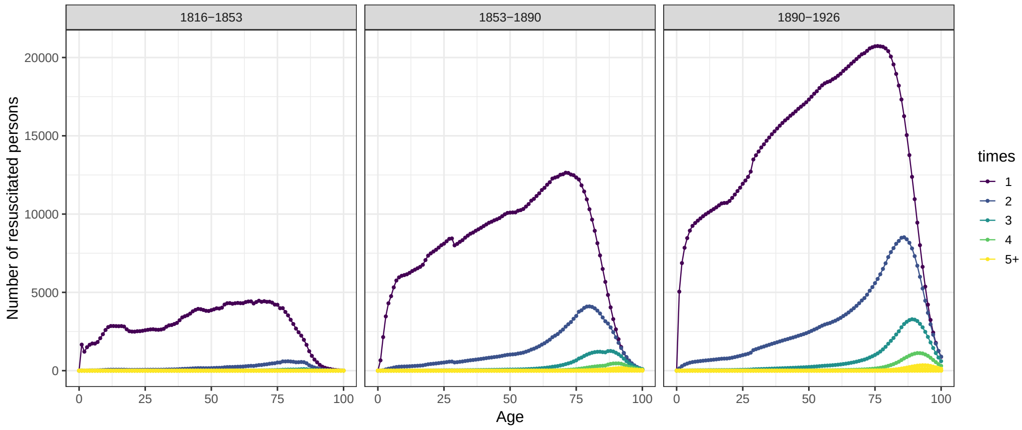
Figure 1: Intensity of lifesaving force, females, 1816-1926, France



The number of times new life tickets granted also gradually changes. While averting the first death is more important to the lifesaving process, the relative contribution of saving lives more than once increases for the most recent cohorts. Because deaths are not avoided, but merely postponed, this suggests that the structure of lifesaving is changing.

In the case of France, as shown by the Figure below, the proportion of total life expectancy lived by the resuscitated at each state indicates the increase in the relative importance of being saved more than once, with the most recent cohorts having survivors who were granted 3,4, and even 5 new tickets to life.

Figure 2: Number of times the resuscitated had their deaths averted, females, 1816-1926, France



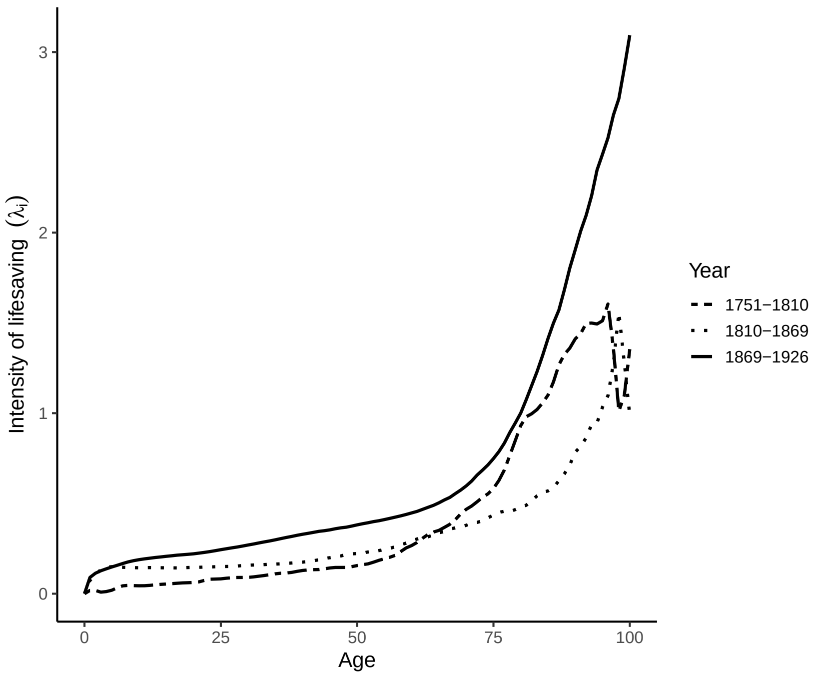
When we decompose this improvement in terms of how may years those who were saved n times expect to live in each state, the number of life years expected to live for those who were saved twice between the 1853 and 1890 birth cohorts is 1.34 years, while this figure increases to 3.02. So not only more new tickets are granted, but their value in terms of life years has also increased for each state. Of all progress French women faced between those who were born in 1816 to those who were born in 1853, the majority of improvement in life expectancy at birth was due to saving lives once (99.50 per cent), while this value declines to 94.3 for 1890 and 1926 birth cohorts. It is true that the most recent birth cohorts also faced the highest mortality improvement, with the difference in life expectancy at birth of 18.18 years. However, the nature of this improvement could be such that the majority of gains were also due to saving lives once, but results suggest that despite saving lives once still drives most of the difference, the contribution of granting the second or third chance to live start to become important.

Table 1: Mortality improvement and life years lived in each resuscitation state i, females, France

	Life expectancy			Decomposing improvement			
Birth Cohort	ex^*_0	ex_0	$ex^*_0 - ex_0$	τ_1	τ_2	τ_3	**%diff**
1816-1853	42.88	39.83	3.05	2.84	0.19	0.02	99.50
1853-1890	52.52	42.88	9.64	7.90	1.34	0.38	96.7
1890-1926	70.7	52.52	18.18	14.16	3.02	0.93	94.3

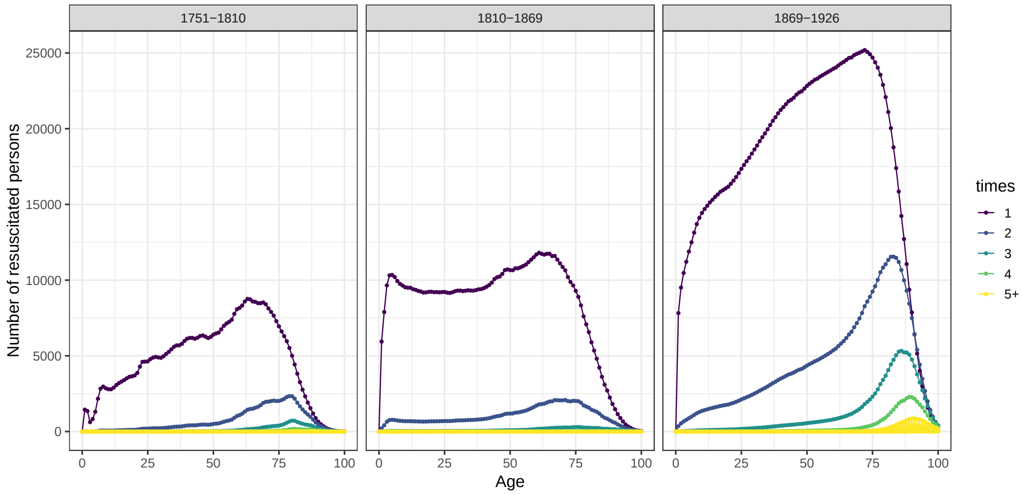
The case of Swedish women is different, with the most recent birth cohorts improvement from 1869 to 1926 being subject to the highest intensity of lifesaving at all ages, with the gains after age 60 incredibly steep.

Figure 3: Intensity of lifesaving force, by birth cohort, 1751-1926, Sweden



In addition, the contribution of being saved two, three, four and even more than 5 times is not negligible for explaining improvement between the cohorts who were born in 1869 and those who were born in 1926.

Figure 4: Number of times the resuscitated had their deaths averted, by birth cohort 1751-1926, females, Sweden



Decomposing the difference in life expectancy at birth also indicates how the relative contribution in terms of life years lived for the second and third resuscitation states increases, while the importance of saving lives once loses force (from explaining 97.9 per cent of the total difference to 91.50 per cent for the most recent cohort improvements).

Table 2: Mortality improvement and life years lived in each resuscitation state i, females, Sweden

	Life expectancy			Decomposing improvement			
Birth Cohort	$ex^*{}_0$	ex_0	$ex^*{}_0 - ex_0$	τ_1	τ_2	τ_3	**%diff**
1751-1810	41.31	35.8	5.55	4.66	0.69	0.16	97.9
1810-1869	50.75	41.33	9.40	8.27	1.03	0.12	97.7
1869-1926	74.81	50.8	24.10	17.67	4.55	1.75	91.50

These results indicate that the resuscitation approach can yield interesting insights for our understanding of the changing structure in mortality improvement and its linkages to population heterogeneity

J. W. Vaupel, Manton **and** Stallard 1979. If mortality rates are reduced, some people will have their lives saved one, some twice, and some many times before they finally die, and other people will die at the same age they would have died before. Understanding how this process takes place of paramount importance to appropriately tackling population ageing and assessing which population subgroups need policy targeting

J. Vaupel 1986.

This process also depends on the frailty distribution of the population and if those who were granted new chances experience a difference hazard of dying than those who were not resuscitated. Frailty is still not integrated in this work, as this first definition assumes that the resuscitated face the same remaining life expectancy as those who were not. We are currently improving the approach and incorporating the concepts of frailty and heterogeneity in the model.

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