Effect of marital status on death rates.  
Part 2: Transient mortality spikes

Peter Richmond\textsuperscript{1} and Bertrand M. Roehner\textsuperscript{2}

Abstract
We examine what happens in a population when it experiences an abrupt change in surrounding conditions. Several cases of such “abrupt transitions” for both physical and living social systems are analyzed from which it can be seen that all share a common pattern. First, a steep rising death rate followed by a much slower relaxation process during which the death rate decreases as a power law (with an exponent close to 0.7). This leads us to propose a general principle which can be summarized as follows: “\textit{ANY abrupt change in living conditions generates a mortality spike which acts as a kind of selection process}”. This we term the \textit{Transient Shock} conjecture. It provides a qualitative model which leads to testable predictions. For example, marriage certainly brings about a major change in environmental and social conditions and according to our conjecture one would expect a mortality spike in the months following marriage. At first sight this may seem an unlikely proposition but we demonstrate (by three different methods) that even here the existence of mortality spikes is supported by solid empirical evidence.

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Key-words: death rate, marital status, widowhood, young widowers, response function, transient behavior.

\textsuperscript{1}: School of Physics, Trinity College Dublin, Ireland. Email: peter\_richmond\@ymail.com
\textsuperscript{2}: Institute for Theoretical and High Energy Physics (LPTHE), University Pierre and Marie Curie, Paris, France. Email: roehner\@lpthe.jussieu.fr
Introduction

Merits and shortcomings of the death rate ratio approach

The present paper is a continuation of Richmond and Roehner (2015) which for the sake of brevity, will be referred to as “Paper 1”.

In paper 1 was shown that in all age groups the death rates $d_s$, $d_w$, $d_d$ of single, widowed or divorced persons were higher than the death rates $d_m$ of married persons. The ratios $r_s = d_s/d_m$, $r_w = d_w/d_m$, $r_d = d_d/d_m$ were called death rate ratios (or simply death ratios) with respect to married persons. The important point we note here is that this is not a small effect. Most death ratios are higher than two and they become as high as 5 for young widowers. Gompertz’s law allows conversion of death ratios into what may be called “equivalent aging”. According to Gompertz’s law, after the age of 30, the death rate doubles by 10 years of age. Thus, if the death ratio of a widower of age 30 is equal to 3, Gompertz’s law implies that widowhood will push up his death rate to that of a married man about 16 years older.

From a statistical perspective the death ratios are convenient and effective variables. They are convenient because they can be easily computed from the death rates by age and marital status. They are effective in the sense that they remove the massive effect of aging on death rates. Whereas the death rates of both married and unmarried persons increase exponentially with age, their ratios remain bounded within fairly narrow intervals.

However, the death ratios are also fairly opaque variables which do not tell us anything about the actual mechanism of the FB effect. This is because the death ratios provide only a static picture. They do not say how death rates are affected in the course of time by a change for example in marital status. In other words, they do not tell us how such a transition should be described at the level of a cohort of persons. It is only through a longitudinal analysis in which one follows a cohort in the course of time that one can gain an insight into what really happens.

Life as an equilibrium state in a domain of the parameter space

What is life? This is a question that may be answered in many ways. For the purpose of the present paper it will be sufficient to observe that it is an equilibrium in which a number of parameters remain confined within fairly narrow limits. For instance the body temperature should remain within 35 and 45 degree Celsius. The domain of the parameter space which is compatible with life may be referred to as the life envelope. Three observations are in order in relation with the present study.

\[1\text{A similar expression is used in aviation. The flight envelope or service envelope of an aircraft designates the domain}\]
In contrast with the case of body temperature for which the limits are rather strict, for many other parameters the limits are fairly elastic. Consider the concentration of hemoglobin in blood. Whereas the references values (for women) are 12–15 g per deciliter of blood, life remains possible even for levels as low as 4 g/dL. In addition, such boundaries are also subject to inter-individual variations. The notion of frailty which is often used in relation with elderly persons can be seen as a global contraction of the life envelope.

Medicine focuses on biological parameters. Yet, for human beings social factors are also very important. This is shown very clearly by the fact that (as seen in Paper 1) death rates of non-married persons are two or three times higher than death rates of married persons. In other words, a major change in familial and social ties can drastically affect the life expectancy of people. Because, up to now, we have no means for measuring the strength of social interactions, it is impossible to define a range of reference values for such variables, however one should keep in mind the existence of such limits.

Usually, in the process leading to death it is not just one but several parameters which go beyond their reference intervals. One reason for this is that the parameters are not independent. This collective effect can be summarized by the notion of “will to live”. Testimonies suggest that often the “will to live” disappears one or two months prior to the actual occurrence of death. Although this notion has probably an objective significance, we recognize that (so far) it has not been measured and quantified. The transient death spikes analyzed in the present paper may be seen as an attempt to define this notion quantitatively. A mortality spike reflects a change in the will to live for the simple reason that it covers a time interval (usually a few months) which is too short for new diseases to fully develop. In other words, the persons who die were positioned near the limits of their life envelope.

The previous comments give rise to several unknown questions and open issues. A useful guide to these comes from the observation that there is a close connection between physical systems and systems of living organisms. This is explained in the next section.

The paper is in three parts. In the next section we develop a system theory perspective which will give us a simplified framework for the analysis of systems of living organisms. It will be seen that, the most visible effect of a state transition in a population is often the occurrence of a transient mortality spike. In this way, simply by shedding the items that are unsuitable in the new situation, the system adapts to the environment change. We then analyze several examples of sharp transitions characterized by such transient mortality spikes. This leads us to the formulation of
the Transient Shock conjecture. Finally, we test a key prediction of this conjecture according to which one should expect a mortality spike in the months following marriages. For that purpose we explore the death rate of newly married persons in the months following their marriage. The challenge is to see whether there is a mortality spike or not.

**System theory perspective**

In order to get a broader understanding we will adopt a system theory point of view which means that we will examine several systems during their transition from a state $A$ to a state $B$. Establishing connections between systems which, at first sight, seem very different yet nevertheless follow the same law is typical of the approach used in physics. An apple and the Moon may be very different in appearance, yet as shown by Newton, they are ruled by the same gravitational law. It will be seen that the transient behavior of physical systems is fairly similar to what is observed in the transitions occurring in human systems. For instance when a collection of VLSI (Very Large Scale Integrated) semi-conductor chips are put in operation, there is first a period of high failure rate. This time of excess failure rate which may last for a few months is commonly referred to as being an “infant mortality” phase by reliability engineers.

Evidence taken from physical as well as human systems will lead us to the conjecture that in a transition $A \rightarrow B$ there are usually two steps and not just one.

1. First, there is a short-term transition shock which results in an upsurge of failures.
2. Secondly, there is a long-term change in the failure rate as the system gets adapted to its new state.

The expression “gets adapted” may raise a question. How can there be an adaptation for physical devices? Is adaptation not a feature that is specific to living systems? In the expression “the system gets adapted” the word system does not refer to a single item but to a sample of items, for instance it will designate a batch of, say 1,000, semi-conductor chips. Although these chips look identical and were manufactured through the same production process, they are in fact slightly different. Some have small defects which will drastically reduce their life-time. Little by little the chips with defects will fail and be eliminated. As a result, the set of “surviving” chips will globally gain a smaller failure rate than the initial sample. It is in this sense that the whole set of chips becomes better adapted to its new state.

In passing we note that Darwin’s theory of “survival of the fittest” also applies to this process? Although a little reflection quickly shows that in the present case the catch
**Fig. 1** Successive transition shocks. The figure shows a system of items which goes successively through three environments. Although all of same type, these items are not completely identical. Their variability is represented by their different shapes: circles, ellipses or squares. At each transition the items which are not adapted to the new environment “die” and are eliminated. As examples one can give the following cases. (i) A set of lightbulbs going through three states: \(A=\text{turned off}, B=\text{turned on, 60 volts}, C=\text{turned on, 220 volts}\). (ii) New born babies: \(A=\text{pre-natal}, B=\text{first day of post-natal life}, C=\text{first year of life}\). In the transition \(A \rightarrow B\), the deaths due to “defects” (premature birth, malformations, congenital debility, injuries at birth) represent 94% of the total deaths whereas in the transition \(B \rightarrow C\) these causes represent only 30% of the deaths (Mortality Statistics 1910, p. 154) (iii) a cohort of persons going through three states: \(A=\text{married}, B=\text{widowed at home}, C=\text{widowed in nursing home}\).

**Fig. 2a** Transient response functions. State 1 and 2 characterize two marital situations. One can distinguish two kinds of responses: those with overshoot (red curve) and those without overshoot (green or blue curves). The later converge steadily toward their stationary value. The time constant \(\tau\) defines the duration of the transient response. Thus, the transition defined by the green curve has a shorter time constant than the one corresponding to the blue curve.
Fig. 2b Different transition scenarios. The pure shock scenario 1 has no slow relaxation phase. The smooth change scenario 2 has no steep upgoing phase. The mixed scenarios 3a and 3b have a steep upgoing phase as well as a slow relaxation phase. 3a is observed in the transition married-to-widowed; 3b is observed in the transition single-to-married.

The phrase “survival of the fittest” is nothing but a tautology. For the chips the very fact of surviving also defines the “fittest” chips. For living organisms, one may imagine that generation after generation there is an adaptation to a changing environment. Yet, the example of the sample of chips shows that for selection and adaptation to take place there is no need for any transformation at individual level. The only requirement is that in the initial sample there is a dispersion of some of its characteristics. In the following subsections we give several examples of parallels between physical and biological systems.

**Infant mortality for lightbulbs**

Everybody has observed that most often lightbulbs fail when they are turned on. Why is this so?

When an incandescent light bulb is switched on, one has the impression that the light goes on instantaneously. Yet, physicists know that natural phenomena are never instantaneous. In the case of lightbulbs there are two very different time scales.

- **An electrical time lag** is due to the self inductance \( L \) of the filament. \( L \) may be small but it is not zero. If one assumes that \( L \) is of the order of one micro-Henry and the resistance of the filament at room temperature about one Ohm, the time constant \( L/R \) of the light bulb will be of the order of one microsecond. Although small, such a time lag can be easily measured with an oscilloscope. Modern digital oscilloscopes have sweep speeds ranging from picoseconds per division to seconds per division.

- **In order to emit light a tungsten filament must reach a temperature of about 2,500 degree Celsius.** Needless to say, this takes much longer than a few microseconds. A reasonable order of magnitude is about 100ms. As the filament becomes hotter, the resistivity of tungsten increases strongly; it gets multiplied by a factor of about 10. This means that for at least 10ms the “inrush” current will be some 10 times greater than the standard operating current. In other words, there will be
an overshoot phenomenon in which the current will greatly exceed its steady-state value. That is why light bulbs often fail immediately after being turned on. In more expensive lamps this problem is overcome through a preheating phase during which the voltage will increase progressively.

Incidentally, this example shows that overshooting does not necessarily imply that the response of the system is ruled by a second order linear differential equation. Overshooting proves that the system is not ruled by a linear first order differential equation; however a nonlinear first order equation is clearly not excluded.

This example shows that by observing the response function of a system one can identify and better understand various phenomena which take place in the system. We seek to do the same kind of analysis for groups of persons moving from one marital state to another.

**Bathtub curves**

In a general way, the physical items for which the notions of failure and life-time have a significance are items that cannot be repaired. Examples are light bulbs, fluorescent lamps, electronic chips, hard drives. For such items it is customary to distinguish 3 successive periods.

- After the item has been turned on, there is an infant mortality period characterized by a decreasing failure rate.
- It is followed by a “useful life” marked by a failure rate that is low and relatively stable.
- Finally comes a wear-out period during which the failure rate increases.

Because of its shape with two upgoing sides, this curve is commonly called a bathtub curve. The graph of the mortality rate of many living organisms has a similar shape (see the graph below for human mortality rates).

**Bathtub curve for hard drives**

A physical case of bathtub curve can be observed for hard-drives. The following observation was made in 2013 and relies on a sample of several thousands hard-drives in use at the BackBlaze cloud storage company.

- The so-called infant mortality period lasted 1.5 years and is characterized by an annual failure rate of 5%.
- The useful life lasted also 1.5 years and it has a failure rate of 1.4%.
- Finally, the wear-out period started on average 3 years after operation was started. It is characterized by a failure rate of 12%. During this phase the number of “surviving hard-drives” will progressively decrease at a fixed rate (which means an

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2In this case overshooting occurs for critical- or under-damping and the response involves oscillations which converge toward the steady-state limit.

3On the contrary, for items which can be repaired, such as shoes or cars, the notion of life-time has no real meaning.
exponential decrease). After 4 years in operation about 80% of the devices were still working.

**Bathtub curve for human populations**

The three phases considered in reliability control are clearly visible for human mortality rates particularly if a logarithmic scale is used for the time axis.

![Bathtub curve for human populations](image)

**Fig. 3** Two examples of bathtub curves. Left: Annual failure rate of hard drives used by the cloud storage company Backblaze. The data are based on a set of several thousand drives operating without interruption. The large dispersion is partly due to the fact that the set included drives from different manufacturers. Right: Human mortality rates, male and female, USA, 1923. The decrease with age follows a power law: $y \sim 1/t^\alpha$, $\alpha = 0.88 \pm 0.05$ (with a confidence probability level of 0.95), whereas the increase is an exponential with a doubling time of about 10 years. In 1910 the exponent of the power law was equal to $0.65 \pm 0.04$. *Sources: Hard drives: Beach (2013). Human mortality: (i) Infant mortality: Linder and Grove (1947, p. 574-575). (ii) Adult mortality: Linder and Grove (1947, p. 150).*

**Analysis of transient mortality spikes**

**Birth as first statistical evidence of transient mortality spikes**

The transition from pre-natal to post-natal life is probably the most dramatic change in human existence. Therefore, if our conjecture is correct, one would expect a transient mortality spike of great amplitude. Currently, in the most advanced countries the infant mortality rate (i.e. mortality during the first year) is of the order of 2 per 1,000 live births which is about 10 times higher than the death rate in the age interval 5-14. As shown in the graph below, the death rates reached in the days and weeks immediately after birth are much higher than the infant mortality rate.

**Suicide spike following imprisonment**

The fact of being arrested and incarcerated certainly marks a dramatic change in
Fig. 4  Response function following the transition from gestation to birth. USA, 1923. The graph shows the change in death rate which occurs in the wake of the birth transition. During gestation the fetal death rate is fairly constant. Then, following birth, “defects” which were not of great consequence during gestation suddenly lead to a dramatic increase of the failure rate. In terms of annual death rate, the peak rate is about 3,500 times higher than the mortality rate in the age interval 5-14. In the weeks following birth the death rate has a power law decrease. For the inset log-log plot of the same data the coefficient of linear correlation is 0.996 and the slope is 0.88. It can be noted that there is a similar “infant mortality” pattern for other changes in living conditions and also for the failures of technical devices following operation start. As an example one can mention electronic devices called VLSI (Very Large Scale Integrated) chips (Wilkins 2002). Source: Linder and Grove (1947 p. 574-575)

Suicide spike in the weeks following release from prison

From the perspective of our transition conjecture, there is a phenomenon which is even more revealing because less expected. It is the fact that there is also a suicide spike in the weeks after prisoners are released. As shown by the table below, in the first week, the suicide rate is some 8 times higher than 3 months after release.

Transition from home to nursing home

Numerous observations have shown that when people are moved from their home to an hospital or a nursing home, they experience a substantial increase in their death rate. Two cases will be reported shortly which show that within a few months after admission the increase can be as high as a multiplication by 5 or 10.

Camargo et al. (1945) studied all first admissions of patients over 65 years old to the
Suicide rate of inmates as a function of the time elapsed since their arrest. The data are for the United States in the 1980s. In the two days following incarceration, the suicide rate decreases rapidly. Subsequently, the decrease continues at a much slower rate. After two years the suicide rate becomes almost identical to the rate in the general male population. If one excludes the last two points the decrease roughly follows a power law: $y \sim 1/t^\alpha$ with an exponent $\alpha = 1.2 \pm 0.4$. Sources: Hayes et al. (1988, p. 36); Roehner (2005 a, p. 669-670).

Table 1 Number of deaths per week of ex-prisoners in the weeks after their release.

| Situation       | Suicide: number of deaths per week | Natural causes: number of deaths per week | Accidents: number of deaths per week |
|-----------------|-----------------------------------|-----------------------------------------|-------------------------------------|
| Week 1          | 4.00 [1.00]                       | 4.00 [1.00]                             | 13. [1.00]                          |
| Weeks 2,3,4     | 1.70 [0.42]                       | 2.33 [0.57]                             | 8.3 [0.64]                          |
| Weeks 5-12      | 0.87 [0.22]                       | 1.63 [0.40]                             | 6.2 [0.47]                          |
| Weeks 13-24     | 0.54 [0.13]                       | 0.66 [0.16]                             | 5.9 [0.45]                          |

Notes: The data are for the UK in the 1990s. The numbers within brackets show the data in normalized form (first week=1). The decrease in the number of suicides per week reflects a transient state marked by a reorganization of social ties. For death by natural causes a factor which may play a role is the fact that terminally ill prisoners are often released so that they can die in hospital (incidentally, this “improves” the death record of the prison).

Source: Sattar (2001, p. 34)

state mental hospitals in Maryland. Their average age was 74. 85% of the patients were diagnosed as psychotics. As reported in the graph below they found very high death rates in the month following admission.

A similar study was performed in France by Thérèse Locoh (1972). The average age at admission was 78 years old. The fact that these persons were not psychotic patients certainly explains that the death rates were about 5 times lower than in the previous study. Nevertheless, the peak death rate is about 5 times higher than the
annual rate in the general population of same age.

An objection has been raised by some authors. They said: “It may be that the transfer decision taken by the caregivers (i.e. the relatives who are taking care of the elderly persons) was motivated by a sudden deterioration of the health of the persons”. If that would be the case the mortality spikes shortly after admission would lose their significance in relation with the transfer. This objection can be answered in two different ways.

- First, one should recall that it is within one or two months after admission that the death spike is the most serious. Such a time interval is very short compared to the survival time of most of the diseases which affect elderly persons (e.g. Alzheimer disease, cancer) which is rather of the order of a few years. In other words, even if the health of the persons had been declining it should not lead to death so quickly. In addition, one should keep in mind that most often the admission into a nursing home is subject to a delay due to the existence of a waiting list.

- One must recognize that the previous argument is purely qualitative and for that reason is not completely convincing. A better answer is to focus on cases for which the transfer decision is taken independently of the situation of the persons. That is for instance the case when an institution is closed and all patients must be transferred to other places. Two cases of relocation have been studied and reported.
in the literature: Aldrich et al. (1963) and Killian (1970). Mortality spikes after relocation were reported in both papers. More details are given in Appendix B.

**Transient mortality conjecture**

The previous observation leads us to the following statement.

> “Any abrupt change in living conditions generates a mortality spike which acts as a kind of selection process.”

This statement which will be called the *Transient Shock* conjecture provides a qualitative model which leads to testable predictions.

**Predictions**

The previous observations put us in the same situation as a person who has seen the Sun rise around 7:00 am during 7 days. Naturally, he (or she) will also expect a Sunrise around 7am in the following days. In order to make this prediction the person does not need a mathematical model of the solar system. Incidentally, such a model would need a lot of inputs based on astronomical observations (e.g. the minor and major axis of the orbits) but nevertheless would not be able to predict the length of the day which is a purely empirical parameter.

Apart from the cases already tested, can we make other predictions? Here are a few examples.

- For a person to lose his (or her) job is certainly a major change in living conditions. Therefore, one would expect a transient mortality spike in the weeks following the loss of the job. Does it exist? The short answer is “So far we do not know”. There have been many studies about the suicide rates of unemployed persons. For instance, Weyerer et al. (1995) have conducted a long-term study. Unfortunately the correlation between unemployment and suicide rates are very low and hardly significant (under 0.20). In contrast one would expect a significant suicide spike not in the long run but only in the weeks following the loss of the job. The problem is to find appropriate statistical data.

- For elderly persons, the fact of moving to another area far away from their circle of relatives and friends is a difficult transition for which one would expect a mortality spike.

- For immigrants the fact of leaving their family behind and moving to a country where people speak a different language certainly represents a difficult transition. Some statistical data are available for immigrants who came to the United States at the end of the 19th century or beginning of the 20th century (Nagle 1982, Mortality Statistics 1910, pp. 586-595). It appears that for a broad sample of countries the suicide rate of immigrants is much higher than either the rate in their country of origin or the rate in the United States (see Appendix A and Roehner 2007, pp. 217-
Unfortunately, the data do not allow us to follow this phenomenon in the course of time.

- The transition single-to-married is a major change. Therefore one would expect a mortality spike in the months following the marriage. This is the purpose of the next section.

- The transition married-to-widowed represents a major change. Therefore one would expect a mortality spike in the months following the death of the spouse. This point will be briefly discussed at the end of the next section.

So far, we have mostly focused on death rates. In the following sections we describe cases in which one would expect transient marriage rates. For instance, should we expect a transient remarriage spike after widowhood? We do not know yet. When a widower wishes to get re-married he must first develop a network of friends. This may take some time. Up to now, the only information that we have is the long-term remarriage rate of widowed persons. In 1960 in the United states it was of same order as the marriage rate of single persons (Grove and Hetzel 1968, p. 103). However, around 1850 in the Netherlands, Switzerland and France the remarriage rate of widowers was 3 to 4 times higher than the marriage rate of single persons (Bertillon 1879).

**Mortality spike in the transition “single-to-married”?**

**Why is the question of importance?**

In everybody’s life marriage is certainly a major transition. We know that its long-term effect is to reduce mortality rates by a factor 2 or 3. We attributed this effect to increased interaction. However, this does not necessarily exclude a transient mortality spike in the months following the marriage because it may be that some persons who were well adapted to their non-married status will not be adapted quite as well to their new marital status. The question of whether or not there is a transient shock following marriage is an important point because if the answer is “yes” it will show that mortality shocks do not only occur as a result of bereavement but in fact are brought about by any major change in living conditions.

**Design of the observation**

How can we find out whether or not such an effect exists? It is not an easy task because we are looking for a short term effect; typically, one would expect a time constant of a few months. Moreover, even if the spike reaches a level twice as high as the death rate \( d_s \) of single persons, it will remain low because at that age \( d_s \) itself is fairly small. This means that to get an insight we need large samples.
Fig. 7  **Is there a mortality spike in the aftermath of marriage?** The graph depicts the death rate change in the single-to-married transition. There are two possibilities. (i) Smooth transition (in blue) (ii) Transient shock (in red) during which the death rate climbs above the rate of single persons. Incidentally, it can be observed that the increase with age of the death rate of single persons is much faster than the corresponding increase for married persons, a point which was already highlighted in Paper 1. The data used to draw the figure are for 1996 but the picture would be similar for any other year. *Source: National Vital Statistics Report, Vol. 47, No 9, 10 Nov 1998, Table 21, p. 73.*

As always, there are two methods, namely longitudinal or transversal analysis\(^4\).  

- In principle, longitudinal analysis is possible only in countries where a cohort can be followed in the course of time through the civil registry statistical system, as is for instance the case in the Scandinavian countries. It can be observed that in such a framework the present inquiry should be considerably easier than for the deaths of widowers because in any month the number of newly married people is about 1,000 times larger than the number of newly widowed persons of same age.

- For transversal analysis one needs to design a suitable “experiment”. A possible methodology based on the monthly distribution of deaths will be tried below.

**Semi-longitudinal analysis**

Usually census data cannot be used to do longitudinal analysis because they provide a picture of the population at a given moment. Few questions are usually asked about the past. There is a good reason for that which is the fact that the recollection of people about events that are more than 2 or 3 years old is not very reliable.

Here we will make use of a census question\(^5\) that concerned the recent past: “Did

\(^4\)Transversal (also called cross-sectional) studies refer to the analysis of data collected at a specific point in time.

\(^5\)According to the website of IPUMS, the variable MARRINYR identifies persons who had married within the 12 months preceding the date of the ACS (American Community Survey) interview. Although this survey is carried out monthly, the Census Bureau does not make publicly available the interview months of respondents. Protection of confidentiality is the reason that is put forward despite the fact that it is not obvious why knowing the month of the interview.
you get married within the last year”. If we select the persons who responded “yes” and if among them we select the persons who declared to be widowed at the time of the census interview, we will get the persons who got married and then lost their spouse within 12 months. In other words, we will be able to compare the death rate of married persons in their first year of marriage to the long-term death rate of married people.

The results of this observations are summarized in the graph below. The question about marriage within the past year was asked only in a few censuses, basically the census of 1880 and the “American Community Survey” after 2006. This survey is conducted every month on a different sample of about 300,000 persons. Over the whole year, it concerns about 3 million persons. The definition of the death rate of the persons married and widowed in the same year requires some explanations.

For a given age interval, among the $n_1$ persons who got married in the past year we select the $n_2$ persons who became widowed. The ratio $r = n_2/n_1$ represents a kind of death rate; however its real definition must be considered more closely. Firstly, it is obvious that the death of the partner occurs within a time interval which is smaller...

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should be an issue. It can be observed that, although the term “interview” is routinely used, in fact, the questionnaires are sent out by post or Internet (real interviews are conducted only in a number of special cases). This suggests another reason for not giving the month: although the questionnaires are sent out on the same day, the dates of the replies may cover a fairly broad range, a range possibly extending over more than one month.
than one year. If the marriage occurs toward the end of the year, it must be followed almost immediately by the death of the partner. In order to define this death rate more completely we need to know what is the average time interval between marriage \((M)\) and widowhood \((W)\). In the absence of any contrary evidence it is natural to assume that over 365 days, both \(M\) and \(W\) are distributed uniformly. However, \(M\) and \(W\) are not independent random variables, because \(M < W\). A simulation reveals that in such a situation the average \(E(W - M)\) of the time interval between \(W\) and \(M\) is one quarter of the year. Thus, in order to express \(r\) as an annual death rate, it must be multiplied by a factor \(k_1 = 4\).

There is a second correction which needs to be done. The ratio \(r\) is not really a death rate per individual, but rather a rate for the end of marriage. As the death of any of the two partners will result in ending the marriage, we see that \(r\) actually refers to twice the death rate per person. In order to express \(r\) as a rate per individual it must be multiplied by a factor \(k_2 = 1/2\). Thus, altogether, \(r\) must be multiplied by \(k_1k_2 = 2\).

On the graph for 1880 we can see that the death rate almost reaches a level of 1,000 per thousand. This should not be surprising. Rates higher than 1,000 simply mean that the whole group died in less than one year. For old age the observed values of \(n_1, n_2\) indeed reveal a high mortality. For instance, in the last age group, namely 75 – 84, of the 93 persons who got married in the past year, 61 became widowed in the interval between their marriage and the census interview. By contrast, in the 2008-2010 survey the \(n_2/n_1\) ratios are much lower. Thus in the last age-group, there were 782 persons who got married in the past year and only 31 became widowed prior to the interview.

**Longitudinal analysis**

Usually, censuses do not give any information about death events for the simple reason that the persons who are able to respond are still alive. However, in a few cases a question was asked about possible death events of relatives. That was the case in the American Community surveys which were made after 2006. The question was “Have you been widowed in the past year?” Through another question we are also able to learn for how many years the persons had been married. Taken together, these data allow us to follow the persons in the course of time and to perform a longitudinal analysis.

We considered 5 cohorts \(C_i\) of married persons who got married in 2000, 2001, 2008, 2009 and 2010 respectively. Their death rate was computed as \(d_i = D_i/C_i\) where the \(D_i\) denote the number of spouses who became widowed in 2010. The \(D_i\) are of the order of a few dozens for young ages but become of the order of only one dozen for
old ages. In order to reduce the statistical fluctuations which come along with such fairly small numbers, we lumped together the data for the cohorts 2000 – 2001 and 2008 – 2009. The results are shown in the graph below. One sees that at a given age the death rate decreases with the length of time spent in married status,

Fig. 9a,b  Death rate for married people as a function of age and length of marriage. (a) The green dotted line gives the long-term death rate of married persons. It almost coincides with the death rate of people who have been married for 10 years (black line). On the contrary, the cohort of the persons who got married and widowed in the the same year (red line) displays an inflated death rate, especially for young ages. The vertical dashed line at age 35 corresponds to the section shown in the figure on the right-hand side. (b) The figure shows the death rates experienced by a cohort of age 35 that gets married at time $t = 0$. Immediately after marriage, there is a death-rate spike whose time constant is of the order of one year. Then the death rate converges toward its steady state average which (as we know from Paper 1) is lower than the death rate of never-married persons. Source: The cohort analysis is based on the AC survey of 2010. The data are available on the IPUMS (Integrated Public Use Microdata Series) website of the Minnesota Population Center, University of Minnesota. This ACS-2010 (1 year) file comprised 3,061,735 persons. The transversal analysis which lead to the curve with the stars is based on data given in the “National Vital Statistics Report” of 8 May 2013 (p. 8).

As the existence of a mortality spike after marriage is rather counterintuitive, we need to discuss the reliability of census data. Censuses are conducted with great care but ultimately their accuracy depends on whether or not the respondents answer the questions correctly. In the present case, what is to be expected regarding the ratios $d_i = D_i/C_i$? One expects that $D_i$, the number of persons who became widowed in the year of the survey, will be fairly accurately reported because these are recent events in the respondents’ lives. The same observation holds with respect to marriage for the persons who got married in 2009 or 2010. For more distant years such as 2000 and 2001 the recollection is probably not so good. However, for those years the data can be checked through a comparison with transversal data. The comparison shows that the two sets of data are fairly consistent with one another.
Transversal analysis

Fig. 10  Is there a transient mortality spike in the months following marriage? Horizontal scale: month (1992). Vertical scale: Number of deaths by month for single (black line with squares) and married persons (red line with circles) respectively. The panels show successive age groups. In each age groups there are several hundreds deaths (the smallest number, namely 182, is in the 20-23 age group of married persons). The (blue) dotted curve shows the monthly number of marriages. It can be added that for older age groups from 35 to 44 (not shown) the death numbers of married people do not display any peak. Source: Mortality detail file for 1992 issued by the CPSR (Consortium for Political and Social Research). The file comprises all deaths that occurred in the US in 1992 (altogether there were 2,179,187 deaths).
From the two previous subsections we know that there is a mortality peak in the first year of marriage. The TS conjecture would suggest an even taller spike in the one or two months immediately following marriage. To explore this further is our objective in this subsection.

The idea on which the present transversal analysis is based is to use the seasonality pattern of the marriages. With a uniform distribution of monthly marriages the prospect would be hopeless because it would be impossible to distinguish the deaths due to the transient effect from all others. Fortunately, in the United States the monthly frequency of marriage peaks in May and June. The marriage rate in May-June is about twice the marriage rate in January. These monthly fluctuations are much larger than the seasonal fluctuations of the death rates for which the max/min ratio is about 1.2 (with the maximum in winter and the minimum in summer). Thus, if we see an increase in death numbers in the months following May-June, it may be attributed to a transient death effect triggered by the marriages. Of course, in order to be convincing such an increase must occur in the age groups in which the marriage rate is highest. As a further confirmation test it should not be seen in age groups over 35.

What data do we need for that investigation? We need monthly mortality data by age and marital status. Monthly mortality data are indeed available in the “Vital Statistics of the United States” but they are not broken down by age and marital status. Fortunately, the “Inter-university Consortium for Political and Social Research” (ICPSR) provides a file which will solve our problem. It lists all the deaths which occurred in 1992 and for each of them it gives the age, marital status, cause of death and many other characteristics. The downloaded ASCII zip file had a size of about 50 M; once inflated the size of the file containing the data reached 333 M!

In the summer months (i.e. in the 2 or 3 months following May-June) there appears to be a transient excess mortality of married persons. Moreover this excess mortality does not exists for ages over 35.

It must be kept in mind that for a fraction of the death certificates of married persons who die shortly after their marriage the new marital situation may not have been updated. The death registration procedures may also be different from state to state, but one should not be too surprised to see a May-June peak in the deaths of single persons.

**Comparison of the three methodologies**

Each of the three methods that we used has its merits and its shortcomings.

- The first set of data had the advantage of existing for a census of the 19th century. This gave us the opportunity to check whether the effect exists over a broad
time range.

- The second set of data allowed us to probe different lengths of time spent between marriage and death.
- The results obtained through the third method were more “noisy” than those of the two other methods but this approach had the merit of suggesting that there may indeed be a tall and sharp death rate peak within one or two months after marriage.

**Transient shock after widowhood**

The death of a spouse results in a drastic change in living conditions. The “Transient Shock” conjecture would lead us to expect a mortality spike in the months following widowhood. The transition from single to married status implies (i) a change in individual living conditions (ii) a re-arrangement of ties: weakening of the ties with parents and strengthening of the ties with the spouse. Similarly the transition from married to widowed status implies (i) a change in individual living conditions (ii) a severance of the bond with the spouse and possibly a strengthening of the links with relatives or friends. In addition there is the psychological dimension of the bereavement process.

Although a more “plausible” effect than the marriage shock, the widowhood shock is much more difficult to study statistically. The effect is difficult to measure for the simple reason that the deaths of young widowed persons are much rarer than the marriages of young persons. Of course, the death of elderly widowed persons are not rare but in that case it is difficult to separate the mortality due to aging from the mortality due the widowhood effect. In other words, for elderly widowers the effect is blurred by a high level of “background noise”.

Many studies have attempted to analyze the widowhood effect. Several of them are summarized in Table 2.

Not surprisingly, the most successful study so far has been the one by Thierry (1999). It provided clear evidence of a mortality peak in the first year after the death of the spouse. Unfortunately, because the data that he has been using give only the year of widowhood (and not the exact date) this study cannot tell us what happens during the first months of widowhood. We will leave this question open for a further investigation.

**Conclusion**

The next step would be to build a mathematical model. However, we believe that one should not hurry to do that without a more thorough understanding. So far, we have an overall grasp of the transient shock effect but there are several points which

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6This is of course partly due to the fact that in this approach we did not use a logarithmic scale. When it is the age which is the independent variable the death rate differences for successive age intervals are so large that the random fluctuations become invisible.
Table 2  Studies of the widowhood effect according to the number of deaths of widowed persons

| Reference (first author) | Year of paper | Age | Deaths of widowed persons |
|-------------------------|--------------|-----|---------------------------|
| Mendes De Leon          | 1993         | > 65| 22                        |
| Bojanovsky (*)          | 1979, 1980   | any age | 181                      |
| Young                   | 1963         | > 55| 906                       |
| Schaeffer               | 1995         | > 40| 934                       |
| Kaprio                  | 1987         | any age | 7,635                    |
| Martikainen             | 1996         | > 40| 9,935                     |
| Mellström               | 1982         | any age | 360,000                  |
| Thierry                 | 1999         | > 35| 819,000                   |

Notes: (*) This study differs from the others in the sense that it considered only death by suicide.

remain unclear. For example, the relaxation mechanism, in almost all cases for which sufficiently detailed data were available (birth, arrest, marriage) the death rate seems to decrease as a power-law instead of an exponential. We would like to confirm this feature by studying additional cases and as a second step understand the mechanism behind it.

Appendix A. Effect of external factors on suicide rates

In the subsections entitled “Suicide spike following inprisonment” and “Suicide spike in the weeks following release from prison” we considered the effect on suicide rates of drastic changes in living conditions. In the present appendix we wish to complement these observations with two others: (i) effect of immigration (ii) effect seasonal factors. While immigration certainly entails a transformation in living conditions, it is a change which is less severe than for inprisonment. The change brought about by seasonal factors is even more moderate. Nevertheless, it turns out that these changes have visible effects on suicide rates.

Suicide after moving to another country

To be taken into custody is only one of several possible mechanisms leading to a disruption of social ties; the process of emigration is another one. Back in the 19th century when an individual or a family emigrated from an European country (say Italy for instance) to the United States it implied a sharp interruption in the contacts with relatives and friends left behind. Furthermore, until the language barrier was surmounted it was not easy to establish social links with American people, except of course with other Italian immigrants.

From a network perspective one would expect the suicide rate of immigrants to be inflated by the weakening of their social ties. The graphs (Fig. A1 a,b) show that the
Fig. A1a,b Suicide rate after relocation. The two graphs compare the suicide rates of immigrants after they relocated into the the United States to their suicide rates in their home country. “Aus” stands for Austria, “Boh” for Bohemia, “Hun” for Hungary, “Sca” for Scandinavia, the other labels are self-explanatory. The word “immigrants” refers to all persons born in a foreign country. The graph on the left-hand side is for New York City in the decade 1870-1880 (correlation is 0.70) while the one on the right-hand side is for the United States in 1910 (correlation is 0.85). Sources: (a). Suicide rates in NYC: Nagle (1882), suicide rates in countries of origin: Durkheim (1897), Krose (1906). (b) Suicides in the US.: Mortality Statistics (1910, pp. 586-595); foreign born population by country of birth: Historical Statistics of the U.S. (1975, p. 117); suicide rates in country of origin: World Health Organization (1996).

data points are above the line $y = x$ which means that the suicide rates of immigrants are higher than in their respective countries of origin. In fact, they are also much higher than the suicide rate in the general US population. This suggests the existence of a shock effect although in the present case we do not know its time constant.

Two additional comments should be made.

- The first comment is in answer to a possible objection. It is well known that in European countries the suicide rates are higher for men than for women. Often the ratio is about 2. In the countries of origin there were of course as many males as females. Unfortunately, we do not know the exact sex ratios of immigrants for each separate country; the only available information is the global sex ratio for all immigrants in a given year. Thus, in 1875 there were 61% males while in 1910 their percentage was 73% (Historical Statistics of the United States 1974 p. 112). Can this difference in sex ratios explain that the suicide rates are higher in the US? The answer is no. Replacing 50% by 61% or 73% would result in small adjustments of the suicide rates: some 17% in the case of a population composed of 73% males. However the rates of immigrants are much larger than in the countries of origin: at least 50% and many are of the order of 100% (see for instance the cases of England, France or Germany).

- Apart from suicide, the “Mortality Statistics” of 1910 also gives death data
by country of origin for 28 other causes of death. A natural question therefore is whether the previous analysis can be repeated for other causes. Unfortunately, it would have little significance for the following reasons. Infectious diseases (e.g. typhoid fever, tuberculosis, pneumonia) are dependent upon local conditions which means that higher rates in the US may be explained by fairly poor living conditions of immigrants. On the other hand, the incidence of non-infectious diseases such as cancer or heart disease is highest in old age. Yet, at their arrival in the US about 85% of the immigrants were in the age group 15-44. In other words, death by cancer or heart disease will mostly affect persons who have been in the US for 20 or 30 years and for whom the transition shock is old history.

**Sensitivity to exogenous factors increases with age**

As is well known, suicide rates display a seasonal pattern, with a minimum in December and a maximum in April-May. In spite of the fact that this effect has been known for over a century and a half, we do not yet know on what mechanism it relies. The only clear conclusion is that monthly suicide rates are significantly correlated with the length of the day. For our present purpose the only assumption that we need to make is that the seasonal pattern is due to exogenous factors. Then, keeping in mind the conclusions drawn from our former observations about the frailty of elderly persons one would expect such persons to be more sensitive to seasonal factors than are younger persons.

In order to see if this is confirmed by observation, we computed the correlation $C(\text{age})$ between monthly suicide numbers in a given age interval and the length of day. It turns out that for young persons, say under 30, $C(<30)$ is almost zero. On the contrary, $C(>60)$ is quite significant which means that the suicides of persons over 60 display a clear seasonal pattern.

These results are summarized in Fig. A2. It shows that $C(\text{age})$ increases fairly steadily with age.

If one wishes a physical analogy for this effect one can consider the following situation. Objects belonging to the Kuiper Belt which is located beyond Neptune experience a weak solar attraction; as a result, their trajectories will be strongly affected by the movements of their nearest neighbors. On the contrary a planet like Mercury has a strong gravitational bond with the Sun and will be little affected when a comet comes close to it.

One must recognize that at this point the explanation regarding the seasonal effect is rather a conjecture. Before it can be accepted, it must be confirmed by supplementary evidence. For instance, our previous argument would lead to the prediction that elderly immigrants experience a higher jump in suicide rates (with respect to the rate
Fig. A2 Correlation of monthly suicides with day-length, Germany, 2004 The correlation with day length is a measure of the amplitude of the seasonal pattern of suicide rates. The graph shows that whereas the seasonal pattern is almost nonexistent for young persons its amplitude steadily increases with age. The same kind of evidence is available for the United States. Sources: Statistisches Bundesamt

in their country of origin) than young immigrants. Unfortunately, this prediction is difficult to test. The obstacle is not only that the required data may not be available, rather they may not exist. Indeed, historically there were much less elderly immigrants than young immigrants which means that the numbers may just be too small to provide reliable suicide rate estimates.

Appendix B. Former studies of elderly people’s relocation

In the subsection entitled “Transition from home to nursing home” we described the results obtained in two studies, namely Camargo et al. (1945) and Locoh (1972). In the present appendix we wish to review a number of other landmark studies. In particular we will try to explain how, over the past three decades, the interest of US researchers shifted away from the investigation of mortality effects and concentrated instead on more qualitative features.

First, we wish to describe in more details the studies already mentioned about the relocation of elderly persons.

Mortality spike in the relocation of elderly patients. Observation 2 (1968)

In 1968 the Stockton hospital in California decided to close part of its facilities for elderly persons. As a result, 600 geriatric psychiatric patients were transferred to other state hospitals. A paper by Eldon Killian (1970) reported the effects of such transfers on the mortality rate of the patients.
The data referring to this observation are summarized in the table below. As already observed, the mean age of those who died was higher than the mean age of the other patients. However, this difference can only explain a factor 1.40 in the death rate ratio whereas the death rate ratio with respect to those who did not move was in fact as high as 3.95.

| Table B1 | Transition shock for relocated hospital patients. California, 1968 |
|----------|---------------------------------------------------------------------|
|          | Number | Percent | Average age | Deaths within 4 months | Death rate (per year and per 1,000) |
| Patients who were moved | 144 | 61% | 74.2 | 14 | 292 |
| Patients who did not move | 362 | 55% | 73.6 | 9 | 74 |

Notes: In spite of the fact that the two groups were fairly similar in terms of age and sex proportion, the death rate of the persons who were moved was about 4 times higher than for those who did not move. As a matter of comparison, in 1970 the death rate (per year and 1,000 people) of persons aged 74 in the general US population was comprised between 46 for females and 74 for males.

Source: The data were taken from Killian (1970), but we lumped together the results for 3 subgroups which, individually, were too small to be really significant.

**Backpedaling in the decades following 1975**

Around 1975 there was a marked turn in the US literature about the effects of relocation on elderly people. Whereas before the 1970s clear evidence of relocation mortality spikes has been given in numerous papers, in the following decades the study of the mortality effect was dropped and research refocused on what became known as the “relocation stress syndrome”. As suggested by the word “stress” such studies were mostly qualitative.

In fact, in spite of the strong evidence provided by earlier papers, the very existence of the relocation effect was put in doubt as can be seen from the titles of the following papers: “The relocation controversy” (Horowitz et al. 1983), “Relocation stress syndrome in older adults transitioning from home to a long-term care facility: myth or reality?” (Walker et al. 2007).

Did these studies really contradict earlier ones. If one excepts a few cases (one of which is discussed below), they were simply looking into another direction. Thus, the paper by Walker et al. (2007) relies on the interviews of 16 residents of long-term care facilities that were conducted between 2 to 10 weeks after admission. Even with the very high death rates observed previously one would not expect many deaths for such a small sample. With an annual death rate of 60% (about 6 times the rate in the general population) the expected number in this 8 week time interval would be $0.6 \times 16 \times (8/54) = 1.4$. In addition, the very fact that these persons could be
interviewed suggests that they were in good mental shape which means that they were not the most at risk.

In the same line of thought, it can be mentioned that some statistical data about nursing homes reported in the “Vital Statistics of the United States” seem doubtful. Thus, on page 379 of Vol.II, Part A of the issue of 1993, one reads that 2,622 hospital inpatients (i.e. remaining at the hospital overnight) committed suicide whereas in nursing homes there were only 81. The total number of deaths in nursing homes was 0.4 million which suggests that their total resident population was about 4 millions (admitting a death rate of 100 per 1,000). Thus the 82 suicides would correspond to an annual suicide rate of $\frac{82}{40} = 2.0$ per 100,000, a rate at least 10 times lower than in the general population of same age. A possible explanation was given in a book by Ms. Kayser-Jones (1981, p. 65):

During the course of my field work at Pacific Manor, (a nursing home in California) I observed that on several occasions when patients became terminal, they were transferred to an acute-care hospital. Many of these patients died shortly after transfer from the nursing home. Thus, the number of transfers may conceal the true number of deaths.

**No mortality in the relocation of elderly patients? A puzzling observation**

As another illustration of the back pedaling process described above it can be mentioned that a study by Markson and Cumming (1974) of a transfer of 2,174 psychiatric patients did not find any mortality spike in the months immediately following the transfer. As such a result is in complete contradiction with the observations described in previous subsections, it cannot just be reported without further discussion (as is done in several review papers). One must try to understand why this observation led to a completely different results. There can be no science if unexplained contradictory results are allowed to coexist.

This case differs from those considered previously in several respects.

- The patients were about 20 years younger than in previous studies. Their mean age was 55. Only 7.5% of them were over 75.
- On p. 319 the authors say that patients with “obvious physical stigmata” of imminent death were barred from being transferred. However, they give no further explanations about this selection process, for instance they do not say how many patients it did concern.

Moreover, in two of the tables there is a fairly mysterious category entitled “Transferred and readmitted”. It comprises 107 patients but not a single death occurred in this group during the 11 months covered by the study.\(^7\)

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\(^7\)The mean age in this subcategory of patients is not given but we may assume that it was close to the mean age of 55 in the whole group. Thus, based on the death rate in the general population, one would expect 2 deaths in 11 months.
• One of the authors, Elizabeth Markson, belonged to the team of the “New York State Department of Mental Hygiene” which planned and organized the transfer. As a matter of fact, politically this transfer was a sensitive issue because it was made necessary by a drastic reduction in state funding. At that time, in 1974, the notion of conflict of interest was not quite as common as it would become in subsequent decades but from the first to the last line the paper reads as an advocacy of the way the transfer was organized.

These explanations do not solve the mystery completely. The most surprising piece of evidence is the fact that in the group of 117 women over 75 (the mean age is not given) there was not a single death in the month following the transfer and only 2 in the two following months. If we assume a mean age of 85, the death rate of women (in 1970) in the general population is found to be about 10% (Historical Statistics of the United States p. 62). Thus, for 117 females over 3 months there should be \((3/12) \times 1.17 \times 10 = 3\) deaths. In other words, instead of a mortality spike we see a death rate that is lower than in the general population.

Appendix C. Observation of post-widowhood mortality

In the subsection entitled “Transient shock after widowhood” we listed several papers in which the authors tried to measure the mortality spike following widowhood, but we did not summarize their results. As already mentioned, in such studies the main obstacle is to collect enough data to be able to draw meaningful conclusions. This difficulty is explained more fully in the next subsection.

Rarity of statistical events for young widowers

After an age of about 30, according to Gompertz’s law (Gompertz 1825), the human death rate as a function of age displays an exponential increase. Basically it is multiplied by a factor of the order of 2 every 10 age-years. Thus, in 2011 in the 28 countries of the European Union, whereas the death rate of men was 0.90 per 1,000 in the age group 30 – 34, it reached 28.4 in the age group 70 – 74.

This observation has an important implication for any investigation of the death of widowed persons. Indeed, it shows that in young age groups (say under 40) the joint events \(E_2\) consisting in the death of a spouse followed some time later by the death of the widowed person will be very rare events.

For instance, how many \(E_2\) events will there be if for the purpose of such an investi-
gation one follows a group of 1 million married persons in the age interval $30 - 35$ over a period of 10 years? For the sake of simplicity we can assume that the death rate is 1 per 1,000 for married persons and 3 per 1,000 for widowed persons. Every year there will be about $10^6/1,000 = 10^3$ widowed persons and only 3 deaths of widowed persons. In order to be able to get a reasonable estimate of the distribution of the death rate as a function of time spent in widowhood one would need at least 100 deaths of widowers per year.

Event scarcity is a big obstacle. This is not only true in the social sciences but also in the natural sciences. For instance, the scarcity of supernovae in the vicinity of the solar system is a big hindrance for the detection of gravitational waves. Similarly, the fact that neutrinos have very few collisions with the medium through which they travel is a major difficulty for neutrino physics.

How is it possible to overcome this difficulty? One can think of four possible ways.

1. The first method which comes to mind is just to increase the size of the age groups by studying countries with large populations. There is another hurdle, however, which comes from the fact that usually death certificates do not include any information about the number of years that the deceased has spent in widowhood.

2. Suppose that at time $t_0$ there is a sudden massive and temporary increase in the mortality rate of young people (as for instance in October 1918 due to the influenza epidemic). This will lead to a jump in the number of widowed persons. Because these persons have an inflated death rate we can hope to detect its effect indirectly.

Data sources

Basically, two kinds of sources can be used. (i) Deaths can be recorded in a limited cohort of widowed persons followed over several years. Examples of this kind are the studies of Young et al. (1963), Bojanosky (1979, 1980), Mendes de Leon et al. (1993), Schaeffer et al. (1995), Martikainen et al. (1996). (ii) Deaths of widowed persons can be identified and selected from vital statistics, more precisely from the computer files of death certificates. Then, after these persons have been identified they may be linked to their spouse through a computerized Central Population Registry. Such a registry does exist only in some countries, particularly in the Scandinavian countries.

Studies which rely on vital statistics have a great advantage over studies in which a limited cohort is followed in the course of time, in the sense that the number of persons involved is much larger, typically of the order of several millions instead of a few thousands.

In Table 2 various studies were ranked according to the total number of deaths of
widowed persons involved. However, a large number of deaths is not enough to make a good sample, age is quite as important. For a sample of widowed persons over 80 there would of course be many deaths but most of them would be due to old age. In other words, without enough young participants the phenomenon that we wish to observe would be largely hidden by the Gompertz effect.

One should also recall that in order to determine the shape of the mortality spike the deaths of widowed persons must be sorted by age and by duration. This was done by Thierry (1999) for post-widowhood durations of one or more years. This study is summarized in the following subsection.

**Response function on a yearly time scale**

To our best knowledge, for a time resolution over one year, it is the study by Thierry (1999) which provides the most accurate results. This is not only due to the high numbers of events but also to the way in which they are analyzed. Two points are of particular importance.

- As age is a key variable it is crucial to perform a 2-dimensional analysis with respect to both age and length of widowhood. Thanks to a large number of events, Thierry was able to distinguish as many as 6 age-groups and 7 intervals for the length of widowhood.

- It is important to present the results of the analysis in terms of death rate ratios $w/m$ of widowers with respect to married persons. Why?

The reason can best be explained by comparing this measure to another one that is commonly used, namely the standardized mortality ratio (SMR). To get the SMR the death rate of widowers is divided by the death rate of the general population of same age. Such a denominator is not as stable yardstick, however. For instance, for the US population of 1970 in the female age-group 35-44, the non-married represented 14% whereas in the age group over 65 the same component represented 64%. Thus, the SMR would fail to capture the effect that not-being married has on death rates. Two comments are in order regarding the graph presenting the results obtained in Thierry’s study.

- The point corresponding to the first year of widowhood is the most important because it gives the amplitude of the phenomenon. At the same time, it is also the one which can obtained in the most straightforward way. Why?

As already emphasized in Part 1 of this study in computing the death rate of widowers, the tricky part is the determination of the denominator that is to say the number of widowers. However, whereas the total number of widowers is difficult to know, the widowers who are in the first year of widowhood that is to say the new widowers can be counted easily through the death certificates of the deceased spouse. Then, in the following years, this cohort of new widowers will shrink due to three
Fig. C1 a,b,c Response functions of widowed persons following death of spouse. France, 1969-1974, 1989-1991. The response function gives the death rate ratio $w/m$. The two thin (green) lines are time series of the deaths which occurred in the periods 1969-1974 and 1989-1991 respectively. The thick lines correspond to their averages and the error bars are for a confidence probability level of 0.95. As a matter of comparison, the dotted curves show the average death ratios computed from transversal data. Sources: Averages over widowhood length: 35-44: Richmond and Roehner (2015, Table 5, USA); 45-54 and 55-54: Vallin et al. (2001, Table B and D, p. 318 and 320). Response functions: computations by the authors based on tables 4 and 5 of Xavier Thierry’s paper (1999).
effects: remarriage, death and emigration. Of these factors it is emigration which is the least documented. How important was it? In the years covered in the graph it was not uncommon for people who have been working in France to return to their home country (e.g. Algeria, Portugal, Morocco or Tunisia) after retirement. Of the three age groups that we considered, one would expect that this phenomenon will mostly affect the oldest, namely 55-64. Xavier Thierry solved this problem by making an educated guess based on data from the census of 1990.

- The individual curves (thin lines) display few significant fluctuations. As a matter of fact, the error bars are smaller than those in the graphs of Part 1. At first sight, this may seem surprising because here, the analysis is more detailed and thus necessarily relies on smaller number. One can give two answers.

The first answer is that the present analysis was limited to persons over 35. In this way one avoids the youngest age groups for which the fluctuations are largest.

Secondly one must recognize that the data computed for the two time intervals (i.e. 1969-1974 and 1989-1991) are certainly highly correlated for the simple reason that the same computation procedure was used. Thus, a factor like for instance emigration was treated in the same way in the two periods even though in reality it may have experienced fluctuations. In other words, the error bars may underestimate the real fluctuations.

Why did the study by Thierry (1999) not provide a time resolution better than one year. It seems that the problem came from the fact that the author got the information about widowhood from the death certificates of the widowed persons (rather than by retrieving the death certificates of the spouses as explained above) but that only the number of years in widowhood were recorded, not the exact date of the death of the spouse.

**Is there a short-term spike immediately after bereavement?**

In the previous subsection we have seen that in the 12 months following the death of a spouse there is an increase in the death rate of widowed persons which is then followed by a long phase of decrease. This shows that:

- The time constant of the upgoing phase is shorter than 12 months. Needless to say, one would like to know if it is of the order of a few days, a few weeks or a few months.
- The relaxation time of the downgoing phase is of the order of several years.

The observations of mortality spikes described at the beginning of this paper suggest similar spikes immediately after bereavement. Is this conjecture supported by statistical evidence?

In the following subsections we give the results obtained in three studies.

(a) The first study is for death rates by all causes; it suggests an upgoing time
constant of the order of 6 months and a relaxation time of the order of 2 years.

(b) The second study is for suicides only; it suggests an upgoing time constant shorter than 6 months and a relaxation time constant of the order of 2 years.

(c) The third study gives results for death by various causes. For death by disease (e.g. heart disease) it suggests upgoing and downgoing time constants of a few days. For death by suicide the time constants are the same but the amplitude of the death rate spike is about 40 times larger.

A key-question is whether these results are consistent with one another.

The Young et al. study (1963)
The first study giving a closer insight into the timing of the upgoing phase was the pioneering paper of Young et al. (1963).

| Time interval following bereavement (months) | 0 – 6 | 7 – 12 | 13 – 24 | 25 – 60 |
|---------------------------------------------|-------|--------|---------|--------|
| Duration of the time intervals (semesters)  | 1     | 1      | 2       | 6      |
| **Actual deaths of widowers** (age: 55-64, 184 deaths) | 22    | 22     | 31      | 109    |
| **Relative death rate** (per semester and per 100 deaths) | 12    | 12     | 8.4     | 9.9    |
| **Death rate ratio w/m**                     | 1.5   | 1.2    | 1.0     | 1.1    |

Notes: The relative death rates per semester and per 100 deaths of widowers were computed as follows: 
\[(22/1) \times (100/184) = 12.0\]. It shows the distribution of deaths in the course of time independently of their overall level.

Source: Young et al. (1963, p. 455).

The Bojanovsky study (1979, 1980)
One of the clearest investigations has been conducted by J. Bojanovsky (1979, 1980) in Germany. He followed the following procedure.

- For the cities of Heidelberg, Ludwigshaffen and Mannheim he was able to get police reports of suicides that occurred between 1971 and 1975. These reports gave the names and marital situation of the suicides.
- The names of all persons who were widowed or divorced at the time of suicide were recorded and for almost all of them the investigator was able to obtain the dates of the widowhood.

The results are given in the table below.

The Kaprio et al. study (1987)
This study is the only one that we could find which gives data for time intervals after widowhood which are as short as 1 week and 1 month. It relies on a broad sample of 7,635 deaths of widowers which occurred between 1972 and 1976. In the Young et al. study there were only 1,540 deaths of widowers.
Fig. C2  Death response function following bereavement. The graph displays the evolution of the rates for general mortality and suicide following the death of a spouse. The shortest time interval considered was one semester. Sources: Death: Young et al. (1963); suicide: Bojanovsky (1980)

Table C2  Response function to the severance of the marital bond through widowhood or divorce.

| Time interval following severance (month) | 0 − 6 | 7 − 12 | 13 − 24 | 25 − 60 | 61 − 120 |
|-----------------------------------------|-------|--------|---------|---------|----------|
| Actual suicide numbers (and per 100 suicides) |
| Widowhood, males (43 cases) | 17 | 3 | 8 | 8 | 7 |
| Divorce, males (55 cases) | 17 | 5 | 10 | 19 | 4 |
| Widowhood, females (56 cases) | 9 | 5 | 10 | 12 | 20 |
| Divorce, females (27 cases) | 1 | 1 | 7 | 10 | 8 |

| Relative suicide rates per semester |
|-------------------------------------|
| Widowhood, males | 40 | 7 | 9 | 3 | 1.6 |
| Divorce, males | 31 | 9 | 9 | 6 | 0.7 |
| Widowhood, females | 16 | 9 | 9 | 3 | 3.6 |
| Divorce, females | 4 | 4 | 13 | 6 | 3.0 |

Notes: The relative rates were computed as follows: \((17/1) \times (100/43) = 40\). They show the evolution of death rates in the course of time and can be compared to the results obtained by Young et al. (1963). It can be seen that for widowers the rate in the first semester is about 6 times higher than in the second semester. It would be interesting to have detailed monthly data for the first semester but this would require samples at least 10 times larger. For females, the concentration of the suicides on the first semester after dissociation is much smaller. This is not surprising on account of the known fact that females are less affected than males by a rupture of the marital bond. The fairly small size of the samples in number of deceased persons (as given within parenthesis in the first column) shows that one cannot expect too much precision from this investigation. Sources: Bojanovsky (1979, p. 75, 1980, p. 101).
For heart disease the results show a spike in the first week after widowhood. For suicide there is even a much taller spike.

Actually, this paper seems to contain some internal inconsistencies. Therefore, it would be useful to check its results by comparing them with those obtained by Young et al. (1963). This is impossible however because the authors do not give their results in the same form.

- Young et al. give total deaths whereas Kaprio et al. give deaths by separate causes of deaths but do not give a table for total deaths.
- Young et al. give the death rate ratio with respect to married people whereas Kaprio et al. give the Standard Mortality Rate (SMR) that is to say the ratio to the death rate of the total population.

Actually, this lack of comparability is not an isolated case. In the social sciences comparisons are a great source of concern which can be described as follows.

In physics any experimental observation is immediately compared to similar results obtained by other researchers. If there is a marked discrepancy, the experiment is
usually repeated until the cause of the discrepancy has been identified. In the social sciences each and every paper seems to be almost independent from previous studies. Even when previous studies are cited by an author their results are rarely discussed with the purpose to see if they are consistent with the new results obtained by that author.

In the present case, the paper by Kaprio et al. (1987) cites the study by Young et al. (1963) but not the study by Bojanovsky (1980). The Young et al. study is cited in the following way. “Earlier studies on fairly small samples suggest that excess risk is greatest immediately after bereavement (Young et al. and other papers”). As no figures are given it is difficult to know the real meaning of expressions such as “greatest” or “immediately after”. Moreover the authors do not try to put their own results in the same form as those of Young et al. That would be a prerequisite for any meaningful comparison.

Social science review papers are particularly frustrating as far as comparisons are concerned because they compile and list results without describing the conditions under which they were obtained and without trying to explain whether different conditions can possibly explain observed discrepancies.

References
The objective of the comments is to indicate the implications of those studies for the present investigation. They may be removed in the final version.

Aldrich (C.K.), Mendkoff (E.) 1963: Relocation of the aged and disabled. A mortality study. Journal of the American Geriatrics Society 11,3,185-194. [After the closing of the “Chicago Home for Incurables” its patients were relocated to other institutions. This circumstance implies that the relocation was not related to a deterioration of their health.]

Aneshensel (C.S.), Pearlin (L.I.), Levy-Storms (L.), Schuler (R.H.) 2000: The transition from home to nursing home. Mortality among people with dementia. The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences 55,3,152-162. [The results given in the paper are based on the answers provided in a survey of 555 non-hospital caregivers who were selected because they contacted associations concerned with dementia. Such a source of information is certainly less reliable than the medical records available in hospitals. The paper presents a graph which suggests that post-admission mortality is highest in the first month after admission even for persons who were not admitted for compelling health reasons. Unfortunately, not only does the graph not show any error bars but
even the data points themselves are not displayed.]

Beach (B.) 2013: How long do disk drives last?

The website: https://www.backblaze.com/blog/how-long-do-disk-drives-last/ provides data covering a 4-year period at the cloud storage company Backblaze.

Bertillon (J.) 1879: Les célibataires, les veufs et les divorcés du point de vue du mariage. [Attitude with respect to marriage of non-married, widowed and divorced persons.] Revue Scientifique de la France et de l’Etranger 8,33,776-783.

Bertillon (L.-A.) 1872: Article “Mariage” in the Dictionnaire Encyclopédique des Sciences Médicales, [Encyclopedic Dictionary of the Medical Sciences]. 2nd series, Vol. 5, p.7-52.

Bertillon (L.-A.) 1879: Article “France” in the Dictionnaire Encyclopédique des Sciences Médicales, [Encyclopedic Dictionary of the Medical Sciences]. 4th series, Vol. 5, p.403-584.

Bojanovsky (J.) 1979: Wann droht der Selbstmord bei Geschiedenen? [After a divorce when is the likelihood of committing suicide largest?]. Schweizer Archiv für Neurologie, Neurochirurgie und Psychiatrie 125,1,73-78.

Bojanovsky (J.) 1980: Wann droht der Selbstmord bei Verwitweten? [After becoming a widower when is the likelihood of committing suicide largest?]. Schweizer Archiv für Neurologie, Neurochirurgie und Psychiatrie 127,1,99-103.

Boyle (P.J.), Feng (Z.), Raab (G.M.) 2011: Does widowhood increase mortality risk? Testing for selection effects by comparing causes of spousal death. Epidemiology 22,1,1-5.

[The study relies on a data set from the Scottish Longitudinal Study which covers 5% of the Scottish population from 1991 to 2001. A total of 14,630 persons were widowed in the sample studied by the authors. Throughout their paper the authors use the notion of hazard ratio which generalizes the notion of death ratio (used in Part I of our study) to various cases of risks, e.g. the risk of non fatal heart attack. When specifically focused on the risk of death, the hazard ratio is identical to the death ratio. The authors found a death ratio widowed/married of $1.40 \pm 0.07$ which is consistent with the results obtained by Young and al. (1965) but, in contrast to them, they found almost no duration effect that is to say no higher mortality shortly after widowhood.]

Camargo (O.), Preston (G.H.) 1945: What happens to patients who are hospitalized for the first time when over sixty-five years of age. American Journal of Psychiatry 102,2,168-173.

[The title is somewhat misleading. These patients were not hospitalized temporarily. They were admitted to mental hospitals from where less than 10% were discharged in subsequent years. The authors gave special attention to the
mortality rate in the months following admission. They found that approximately 16% of all admitted patients died during the first month after admission and 46% had died by the end of the first year.

Durkheim (E.) 1897: Le suicide. Étude de sociologie. F. Alcan, Paris. A recent English translation is: “On Suicide” (2006), Penguin Books, London. [Durkheim showed not only that suicide rates among non-married, widowed or divorced persons were higher than among married persons but also that they were lower among married persons with several children than for married persons without children.]

Farr (W.) 1859, 1975: Influence of marriage on the mortality of the French people (12 p.). Transactions of the National Association for the Promotion of Social Science 1858-1859, 504-520. The paper was republished in 1975 in “Vital statistics, a memorial volume of selections from reports and writings of William Farr”. Scarecrow Press, Methuen (New York). [The style of the report is somewhat outdated and confusing. An illustration is provided by the following excerpt taken from the first paragraph. “The action of the various parts of the body in industrial occupations produces specific effects. Every science modifies its cultivators. The play of the passions transfigures the human frame. How do they influence its existence?”]

Frisch (M.), Simonsen (J.) 2013: Marriage, cohabitation and mortality in Denmark: national cohort study of 6.5 million persons followed for up to 3 decades. International Journal of Epidemiology 1,13.

Gompertz (B.) 1825: On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. Philosophical Transactions of the Royal Society 115,513585.

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Hayes (L.M.), Rowan (J.R.) 1988: National study of jail suicides: seven years later. National Center on Institutions and Alternatives, Alexandria (Virginia).

Helsing (K.J.), Szklo (M.), Comstock (G.W.) 1981: Factors associated with mortality after widowhood. American Journal of Public Health 71,802-809. [The paper is based on the comparison of a sample of 4,032 persons who became widowed between 1963 and 1974 and a sample of same size of married persons. For males, the ratio of death rates of widowed persons to that of married persons is 1.34. The paper is freely available on the Internet.]

Horowitz (M.S.R.), Schultz (R.) 1983: The relocation controversy. Criticism and
commentary on 5 recent studies. The Gerontologist 21,229-234.

IPUMS: Integrated Public Use Microdata Series, University of Minnesota, Minneapolis.

[The IPUMS website offers a set of databases giving individual census records. It covers the United States as well as a number of other countries.]

Kaprio (J.), Koskenvuo (M.), Rita (H.) 1987: Mortality after bereavement. A prospective study of 95,647 widowed persons. American Journal of Public Health 77,3,283-287.

[The study involved the deaths of 7,635 widowed persons. The breaking up by age groups was limited to only two groups: under versus over 65. Like the Martikainen paper, the authors are are rather interested in the distinction between various causes of death.]

Kayser-Jones (J.S.) 1981: Old, alone, and neglected. Care of the aged in the United States and Scotland. University of California Press, Berkeley.

[After staying 3 months in a nursing home in the east of Scotland and 4 months in a private nursing home in California, the author provides a comparative analysis.]

Killian (E.C.) 1970: Effect of geriatric transfers on mortality rates. Social Work, 15,1,19-26.

[The author followed for 4 months some 144 patients who were transferred from the Stockton hospital in California to other facilities. Actually, 387 patients were transferred between January 1966 and March 1968. The author does not say why he limited his study to the 144 who were relocated between January and March 1968.]

Krose (H.A.) 1906: Der Selbstmord im 19. Jahrhundert. [Suicide in the 19th century]. Herdersche Verlag, Fribourg.

Linder (F.E.), Grove (R.D.) 1947: Vital statistics rates in the United States, 1900-1940. United States Printing Office, Washington DC.

Locoh (T.) 1972: L’entrée en maison de retraite. Etude auprès d’établissements de la région parisienne. [Admission into nursing homes. A study of institutions located in Paris and the surrounding area.] Population 27,6,1019-1044.

[The author followed a population of about 600 persons (125 men and 480 women) following their admission into nursing homes.]

March (L.) 1912: Some researches concerning the factors of mortality. Journal of the Royal Statistical Society 75,505-538.

[The paper includes a comparative analysis of mortality rates in France, Prussia and Sweden.]

Markson (E.W.), Cumming (J.H.) 1974: A strategy of necessary mass transfer and
its impact on patient mortality. Journal of Gerontology 29,3,315-321.

[The paper relates the transfer between different hospitals of 2,174 psychiatric patients in New York State. There were two major differences between this study and similar ones. Firstly, the study did not find any mortality spike in the weeks following the transfer. Secondly, one of the authors, Elizabeth Markson, belonged to the team of the “New York State Department of Mental Hygiene” which planned and organized the transfer. A more detailed discussion is given in the paper.]

Martikainen (P.), Valkonen (T.) 1996: Mortality after the death of spouse. Rates and causes of death in a large Finnish cohort. American Journal of Public Health 86,8,1087-1093.

[This study relied on a total of 9,935 deaths of widowed persons which is a substantial number but, in contrast with most other studies, it found only a small difference in death ratio during the first 6 months after widowhood and the subsequent 5 years, namely 1.29 compared with 1.19. One may wonder why? The reason is fairly simple. The authors did not make an analysis by age groups but instead lumped all ages together. As the sample contained people who were between 40 and 89 at the end of the study, the results are completely dominated by the deaths of old persons, say over 75. It is not surprising that in such an age group, the mortality ratio is of the order of 1.3 and that it decreases very little in the course of time. One can regret that the authors did not extract from their study relevant data for younger age groups.]

Mellström (D.), Nilsson (A.), Odén (A.), Rundgren (A.), Svanborg (A.) 1982: Mortality among the widowed in Sweden. Scandinavian Journal of Social Medicine 10,33-41.

[The study followed 360,000 individuals aged between 50 and 90 who were widowed in Sweden at some point between 1968 and 1978. It showed a peak in the mortality risk during the first 3 months. For widowers the amplitude (with respect to married persons) was 1.48 while for widows there was a peak of smaller amplitude, namely 1.22.]

Mendes de Leon (C.), Kasi (S.), Jacobs (S.) 1993: Widowhood and mortality risk in a community sample of the elderly. A prospective study. Journal of Clinical Epidemiology 46,6,519-527.

[The study involved only 22 deaths of widowed persons.]

Mortality detail file for 1992 (ICPSR 6798) 2001: Published by the US National Center for Health Statistics.
[It is the user guide of an electronic file of all the deaths that occurred in the United States in 1992. It gives the meaning of the codes of all variables. The
same kind of data is available on the website of the “Consortium for Political and Social Research” for all years from 1968 to 1992.]

Mortality statistics: review of the Registrar General on deaths in England and Wales. Series DHI, Number 16. Her Majesty’s Stationary Office, London.

Mortality Statistics 1910 (published in 1912): Bulletin 109. Bureau of the Census, Government Printing Office, Washington DC.

Nagle (J.T.) 1882: Suicides in New York City during the 11 years ending Dec. 31, 1880. Riverside Press. Cambridge (Ma.).

National Center for Health Statistics (NCHS) 1970: Mortality from selected causes by marital status. Vital and Health Statistics, Series 20, number 8.

Parkes (C.M.), Benjamin (B.), Fitzgerald (R.G.) 1969: Broken heart. A statistical study of increased mortality among widowers. British Medical Journal 1,740-743.

[This is the continuation of the Young et al. (1963) study. The same sample was observed over 4 more years i.e. a total of 9 years after the death of the spouse. Over these 4 years the death ratio widowed/married was comprised between 0.90 and 0.95.]

Registrar General 1971: Statistical Review of England and Wales. Part III. Office of Population Censuses and Surveys. London.

Richmond (P.), Roehner (B.M.) 2015: Effect of marital status on death rates. Part 1: High accuracy exploration of the Farr-Bertillon effect. Preprint, May 2015.

Roehner (B.M.) 2007: Driving forces in physical, biological and socio-economic phenomena. Cambridge University Press, Cambridge.

Sattar (G.) 2001: Rates and causes of death among prisoners and offenders under community supervision. Home Office Research Study 231.

Schaeffer (C.), Quesenberry (C.), Wi (S.) 1995: Mortality following conjugal bereavement and the effects of a shared environment. American Journal of Epidemiology 141,12,1142-1152.

[The study involved 934 the deaths of 934 widowed persons.]

Statistisches Jahrbuch für die Bundesrepublik Deutschland 1978: Stuttgart.

Stroebe (W.), Stroebe (M.S.) 1987: Bereavement and health. The psychological and physical consequences of partner loss. Cambridge University Press, Cambridge.

[The book is mostly concerned with psychological and other qualitative aspects. Although short (p. 151-167), the review of the quantitative evidence about the mortality of widowed persons is quite useful. It can be noted that the book has a broad reference section which contains about 600 entries.]

Thierry (X.) 1999: Risques de mortalité et de surmortalité au cours des 10 premières
anniées de veuvage. [Excess mortality during the first 10 years of widowhood.]
Population 54,2,177-204.

This is a key-paper in the investigation of the impact of widowhood duration on the death rate of widowers. It is not based on a sample but on the whole French population followed over 8 years. It takes advantage of the fact that, in contrast with most other countries, French death certificates contain information about widowhood length.

Thierry (X.) 2000: Risques de mortalité et causes médicales des décès aux divers moments du veuvage. [Mortality and causes of death throughout widowhood] Gérontologie et Société 95,27-43.

Vallin (J.), Meslé (F.), Valkonen (T.) 2001: Tendances en matière de mortalité et mortalité différentielle. Editions du Conseil de l’Europe, Strasbourg. An English version was published under the title “Trends in mortality and differential mortality”.

Walker (C.A.), Curry (L.C.), Hogstel (M.O.) 2007: Relocation stress syndrome in older adults transitioning from home to a long-term care facility: myth or reality? Journal of Psychological Nursing and Mental Health Services 45,1,38-45.

Wang (L.), Xu (Y.), Di (Z.), Roehner (B.M.) 2013: How does group interaction and its severance affect life expectancy? arXiv preprint 1304.2935 (9 April 2013)

Weyerer (S.), Wiedenmann (A.) 1995: Economic factors and the rates of suicide in Germany between 1881 and 1989. Psychological Reports 76,1331-341.

Wilkins (D.J.) 2002: The bathtub curve and product failure behavior. Part I: The bathtub curve, infant mortality and burn-in. Hot Wire 21 (November 2002)

Young (M.), Benjamin (B.), Wallis (C.) 1963: Mortality of widowers. Lancet 2,254-256.

[This is a longitudinal study. It involved the deaths of 906 widowers. The authors followed over a period of 5 years a sample of 4,486 widowers more than 55 years old and whose wives had died in January 1957. Altogether there were 906 deaths of widowers. In the age-group 60-64 they found a death rate ratio widowed.married of 1.7 in the first six months after the death of the spouse and 1.0 for the remaining time; however, it must be observed that there were only 44 deaths in this age-group.

The problem is that these ratios are too low to account for the ratio of 1.6 given by UK vital statistics data for age groups which cover 5 or 10 years. On average individuals spend 5 years in a 10 year age group. If their death rate is multiplied by $k_1$ over an interval of $m$ months, and by $k_2$ for the remaining months, then for the 5 years during which they remain in the age group the average rate will be multiplied by: $k = m \times k_1 + 54 \times k_2)/60$; for $m = 6$, $k_1 = 1.39$, $k_2 = 1.04$.
one gets: $k = 1.08$.]