How can one explain changes in the monthly pattern of suicide?

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HIGHLIGHTS

- Analysis of the seasonal pattern of suicide.
- The pattern remains strong in some well urbanized countries.
- This observation contradicts common belief in pattern erosion.
- Monthly suicides are decomposed into simpler components.
- Decomposition by age-groups shows only young and elderly matter.

ARTICLE INFO

ABSTRACT

The monthly pattern of suicides has remained a puzzle ever since it was discovered in the second half of the 19th century. In this paper we intend to "explain" not the pattern itself but rather its changes across countries and in the course of time.

First, we show that the fairly common idea according to which this pattern is decaying in "modern" societies is not altogether true. For instance, around 2000, in well urbanized countries like South Korea or Spain this pattern was still as strong as it was in France (and other European countries) in the late 19th century.

The method that we use in order to make some progress in our understanding is the time-honored Cartesian approach of breaking up the problem under consideration "into as many parts as might be necessary to solve it". More specifically, we try two separations of monthly suicides into simpler components: (i) according to suicide methods and (ii) according to age-groups. These separations rely on the introduction of what we call "elementary monthly profiles".

The first separation points out the key-role of hanging and drowning. The second shows the crucial role of the 15–20 and 65+ age-groups.

Then, we present a number of cases in which age-group decomposition provides adequate predictions. It turns out that the cases in which the predictions do not work are newly urbanized countries. The discrepancies may be due to a memory effect which induces a time-lag extending over one or two generations.

Finally, in the light of the new results presented in the present paper, we re-examine the theory proposed by Emile Durkheim.

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1. Introduction

1.1. A long-standing conundrum

Monthly suicide numbers display a seasonal pattern which, more or less, tends to repeat itself annually. This pattern is apparent simply by examining a monthly time-series. It can be detected more clearly by computing the auto-correlation function and the spectral density. The auto-correlation function will be much more periodical than the initial time series and will display a period of 12 months.[1] The spectral density has a main peak for a 12-month period and often a smaller, secondary peak corresponding to a 6 or 7 month period.[2]

Basically, suicide numbers are lowest in December and highest in April–May–June. Although this pattern has been known since the second half of the 19th century (see the work of Morselli [1] and Durkheim [2] we still have no real understanding of this effect.

A paper devoted to this question by Swiss researchers [3] starts with the following sentence. "Seasonality in suicide is one of those topics in epidemiology that we believe to know much about but understand fairly little in actuality". This is a lucid assessment with which most researchers would probably agree. Why is this so?

To the best of our knowledge, the only comprehensive framework on which we can rely is the one proposed by Emile Durkheim. He showed that there is an inverse relationship between the strength of inter-social links (and particularly family links) and the propensity for suicide. This mechanism explains very well a number of observed facts (see for instance [4], Part 3). Does it also explain the seasonal pattern? This point will be discussed at the end of the paper.

1.2. To what extent is there a connection with day-length?

As suicide rates show a minimum in December and a maximum in May the first idea which comes to mind is to think that there is a connection with day-length. Although that connection was already considered by Durkheim, there are two key empirical tests that could not be performed at that time due to a lack of data.

- Is the seasonal pattern of suicide reversed in the Southern hemisphere (e.g. in Australia, Chile or Argentina)? The answer is yes.
- Is the suicide pattern stronger in northern countries (e.g. Alaska, the northern provinces of Norway and Sweden) which have sharper seasonal daylength differences? The answer is no. The seasonal effect hardly changes with latitude. Nowadays, it is almost the same in Alaska and in Florida.

1.3. To what extent is the slow erosion connected with urbanization?

The investigation by Ajdacic-Gross et al. [3] already mentioned above analyzes the decay of the seasonal effect over the past 125 years. After presenting solid evidence of this erosion for Switzerland, the authors conclude by saying that the erosion may be related to the "transformation of a rural society into a modern one".

Durkheim already observed that the effect is stronger in rural areas than in big cities (some of his supporting data will be given later on). The slow erosion seen in Switzerland is also observed in most industrialized countries. For instance, in France where monthly suicide data are available since 1836 one observes that the quinquennial peak–low ratio[3] defined by Ajdacic-Gross et al. decreased from 1.88 to 1.25 during the period 1838–1997, a trend very similar to the one observed in Switzerland: 0.38/century in France versus 0.52/century in Switzerland.

The present author shared the belief that the decay should be attributed to urbanization until coming across suicide data for South Korea, Spain and Turkey. In these countries, in contrast with the cases mentioned so far, there is still nowadays a strong seasonal pattern (Fig. 1). This observation was at the starting point of the present paper.

## 1.4. How can one characterize the seasonal pattern?

The seasonal pattern is completely defined by the 12 monthly suicide numbers. Of course, it would be useful to be able to characterize it with a smaller and more transparent set of parameters. We propose the following:

- The ratio peak/low (P/L) of the highest to the smallest suicide number defines the amplitude of the monthly frequencies. This metric is fairly standard but it is not sufficient for it does not tells us whether the monthly changes are random fluctuations or instead follow a well-defined shape. That is why we add the following indicator.

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[1] Why is the auto-correlation less noisy than the initial series? A simple reason is because it provides a kind of *moving average* over the whole length of the series.

[2] This shorter period may correspond to a secondary peak in August or September. However, this lower peak may or may not exist. Sometimes, as in France during the 19th century, it can be seen only on the suicide series of women. In any case, before trying to explain the secondary peak it seems appropriate to first focus on the main peak.

[3] This peak/low ratio is defined as the highest monthly suicide rate in 12 months divided by the lowest rate. "Quinquennial" refers to the fact that one considers suicide rates which are 5-year averages.
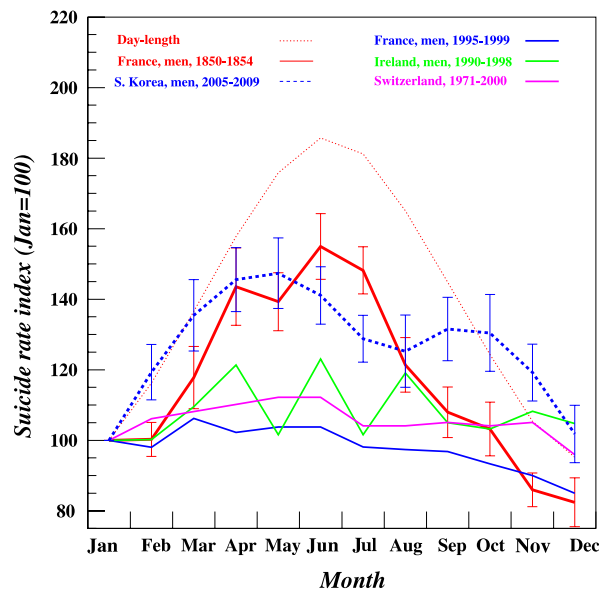
Fig. 1. Monthly suicide pattern in France, Ireland South Korea and Switzerland. In countries like South Korea there is still a strong seasonal pattern in spite of a high urbanization rate. The data for Spain and Turkey are similar to those for Korea; they are not shown here for the sake of clarity but are given in Table 1. All data are for male populations; the data for the female populations are very similar both in shape and in level. The error bars (i.e. $\pm\sigma$) have been drawn only for the curves which have a well-defined shape. The day-length data are for a latitude of 50 degrees (city of Aachen in Germany).
Source: France 1850–1854: yearbooks of the "Compte Général de l'Administration de la Justice Criminelle"; France 1994–1999: INSERM website; South Korea 1994–1999: website of the national statistical institute; Spain 1994: website of the national statistical institute. Ireland: [5]; Switzerland: [3].

- The second indicator is the correlation (*cor*) of daylength numbers with monthly suicide frequencies. It will tell us whether the frequencies display the standard shape with a minimum in December and a maximum near mid-year. Note that, taken alone, this indicator would not be sufficient for it does not tell us anything about the amplitude of the mid-year maximum. Any series that is more or less symmetrical with respect to its mid-year maximum will give a correlation close to one, no matter how small the maximum is.

If one wishes, the two indicators can be combined into a single seasonal index defined as: $s = [(P/L - 1) + cor]Y(cor)$, where $Y(x)$ is the Heaviside function (equal to 0 for $x < 0$ and to 1 for $x > 0$). This parameter will be zero as long as the correlation is not positive and when *cor* is positive it will become higher for a profile of larger amplitude and higher correlation.

1.5. What makes demography a field of interest for econophysicists?

So far there was little interest among econophysicists for demographic issues. That is probably why one of the referees suggested that a section should highlight some of the reasons which make demographic analysis worth of interest in econophysics. Demographic phenomena enjoy several advantages: simplicity, stability, accurate data. Let us explain them briefly.

- **Simplicity** At first sight one might think that demography is indeed too simple and already too well understood to be of any real interest as a research topic. However, this belief does not resist closer examination. In fact, the behavior of even the most basic variables (e.g. marriage rates or fertility rates that is to say the number of children a women has in her lifetime) is not yet understood. As an illustration, one can mention the fact that in Japan many women stop working after getting married which would seem an ideal situation for raising children, yet Japan has one of the lowest fertility rates in the world.[4] Even death rates are not well understood. For instance, why is the death rate (in each main class such as cancer, heart diseases and so on) of widowers or divorced persons two or three times higher than the death rate of married persons?
- **Stability** It is true that the attitudes with respect to getting married, having children or getting divorced may change in the course of time but they change gradually. In contrast, over the past 50 years, there have been major institutional changes in financial markets, e.g. the introduction of high-yield bonds in the 1970s, the introduction of electronic quotations which reduced transaction costs and increased trading volume, the introduction of stock options and other sophisticated securities in the 1990s.
- **Accurate data** Together with price data, demographic data were historically among the first to be recorded by government agencies. Today, they still rank among the most accurately reported statistical data. In addition (in contrast to

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[4] In "Cohésion sociale" Odile Jacob, Paris 2005 I give a graph which shows that in the 1960s and 1970s there were several instances of fertility predictions made by a panel of US demographers for the following 5 years that turned out to be wrong by a wide margin (over 50%).

Table 1
Magnitude of the seasonal suicide effect.
Source: The urbanization rates are from the website "Trading economics" except the figure for France 1850–1854 which is from Ref. [7, p. 259]. The data for suicides over 65 and under 45 are from the World Health Organization, except for Turkey (not available on WHO) which come from the "Turkish Statistical Institute".

Case	Correlation of day-length and monthly suicides	Peak/Low	Seasonal index	Urbanization rate	Ratio of suicides over 65 to suicides under 45
France 1850–1854	0.94	1.82	1.76	18%	0.69
South Korea 2005–2009	0.81	1.47	1.28	82%	0.70
Spain 1980–2004	0.80	1.37	1.18	77%	0.80
Turkey 2000–2004	0.89	1.61	1.50	59%	0.20
France 1995–1999	0.62	1.25	0.87	78%	0.78
Switzerland 1971–2000	0.70	1.17	0.87	73%	1.12
Ireland 1990–1998	0.47	1.23	0.70	62%	0.11

Notes: The seasonal index measures the similarity between the monthly curve and the daylength curve. The table shows that, contrary to what "common sense" may suggest, the magnitude of the daylength effect is fairly independent of the urbanization rate. The numbers in the last column are given in reference with the coming discussion about the influence of age. All data are for men, except for Switzerland which is for males and females together.

many other economic variables, e.g. income or wealth) demographic variables have the same definition in most countries which makes comparative analysis easy and meaningful.

Regarding more specifically the question of suicide there is an additional reason which makes the contribution of econophysicists quite essential. It can be explained as follows.

The pioneers of the late 19th century (e.g. Durkheim or Morselli) used the methodology of doing (and repeating) as many observations as possible. This approach was found quite natural (at least at that time) because it is the core methodology of experimental physics. For that purpose they collected and analyzed data from a great number of countries, e.g. Austria, Bavaria, Britain, France, Italy, Prussia, Saxony, and so on. Nowadays, thanks to the Internet, it has become fairly easy to get data from many countries. Yet, it seems that nowadays the approach used in Durkheim's time is no longer favored by most social scientists[5]: Irish researchers will publish and analyze data for Ireland, similarly Japanese or Swiss researchers will analyze data for their own countries (see the papers by Adjacic-Gross et al., Corcoran et al. and Ohtsu et al.).

Until the last quarter of the 20th century it was widely recognized that Durkheim had opened a new horizon for social research by demonstrating that suicide is a social phenomenon. The reason why Durkheim looked beyond "immediate causes" of suicide is not because he wanted to deny their existence but because such causes are too diverse to be amenable to scientific investigation. Nowadays, however, this conception has been largely forgotten. Most of the research on suicide is focusing on immediate individual causes and in particular on psychiatric disorders.[6] Given that the human brain is probably the most complex system one can imagine, it seems a fairly challenging task to explain suicide by relying on brain disorders. It is true that there have been great advances in medical imaging; the question is whether these tools will be sufficient to understand a system such as the brain. It can be observed that for weather and climate forecasts we have all the data and models that we need, yet prediction remains elusive and it is not only because of the butterfly effect.

2. Breaking up suicide into elementary profiles

The overall number of suicides in a given area is an aggregate variable in which several components are bulked together. These components may not necessarily be ruled by the same mechanism. Suicide by poisoning or by hanging may not follow the same rules. Suicides of 20-year old persons may differ from suicides of 80-year old persons. Combining heterogeneous factors will make the description opaque and ambiguous. On the contrary, in any science, whether physics, chemistry, economics or sociology, one will get a clearer insight by studying simple components rather than mixtures. In the following sections we will try such an approach in two different ways. First, we make a distinction between various suicide methods. Second, we make a distinction between different age-groups (see Table 1).

Every monthly suicide series corresponding to a specific suicide method will be called an *elementary monthly profile*. The same definition applies to monthly suicide series corresponding to a specific age-groups.

These profiles are elementary in the sense that they separate aspects which are otherwise bulked together. However they are elementary only in this relative sense, not in an absolute sense.[7]

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[5] Yet, one should emphasize that *Durkheim's comparative methodology* has recently been revived and used in a masterful way for the analysis of income distribution in a most acclaimed book by economist [14] and Piketty (2014). The same kind of comparative approach had been applied to the analysis of historical events in Ref. [6]. This approach of history (termed *analytical history*) has had few followers so far probably because it goes against the mainstream trend of ever greater specialization, by which we mean that most studies are devoted to a specific phenomenon, in a given time period and in a single country. Alas, as is well known, such single events cannot be studied in a scientific way. They can only be described. In a sense, this is a missed opportunity because the Internet provides a unique and wonderful tool for developing comparative analysis.

[6] Consequently an analysis based on social factors (as proposed in the present paper) has become difficult to publish in mainstream demographic journal.

[7] A similar distinction is made in physics. From molecules, to protons, to quarks particles once thought to be elementary turned out to comprise more elementary components.

Table 2
Effect on the seasonal pattern of changes occurring in suicide methods.
Source: [3] plus personal calculations.

	Peak/Low 1881–1920	Correlation day-length/monthly suicides 1881–1920	Percentage (weight) 1881–1920	Percentage (weight) 1969–2000
Poisoning	1.08	0.43	4%	16%
Hanging	**1.64**	**0.92**	42%	30%
Drowning	**2.16**	**0.92**	23%	11%
Firearms	1.28	0.91	22%	28%
Cutting	1.53	0.72	5%	2%
Jumping	1.45	0.72	3%	12%
Total, 1881–1920				
	P/L	P/L	cor	cor
	exp.	obs.	exp.	obs.
	1.59	1.61	0.980	0.976
Total, 1961–2000				
	P/L	P/L	cor	cor
	exp.	obs.	exp.	obs.
	1.47	1.17	0.97	0.70

Notes: "exp." means "expected", "obs." means "observed". The expected values were computed by combining the monthly profiles of the 6 methods as observed in 1881–1920 with the weight of each method observed first in 1881–1920 and second in 1961–2000. The expected changes account for only a small part (26% for P/L and 5.1% for cor) of the observed changes.
This suggests that there has been a change in the elementary method-profiles; in the present case (because the data are available) this conclusion can indeed be confirmed by direct statistical observation (see the graphs in Ref. [3]).

In order to get profiles which are "more elementary" one may cross-combine several types of attributes. This would lead, for instance, to defining the monthly profile of suicides committed by people in a given age-group (e.g. between 20 and 24) *and* by a given method (e.g. firearm). In addition, factors such as gender or marital status can be specified.

Increasing the number of factors in such a decomposition process will eventually lead to monthly suicide numbers that are too low to permit any clear conclusion to be drawn; basically under 30–40 suicides in a month the noise component becomes overwhelming. That difficulty can, to some extent, be overcome by pooling together the suicides occurring in successive years (as was done in Ref. [3]). Pooling together the suicides occurring in different countries has rarely been done. Actually, it may interfere with the suicide-method attribute because in this respect each country has its own "traditions". Needless to say, pooling is not an ideal solution because by adding up diverse situations it may lower the "resolution" of the data.

3. Decomposition based on suicide methods

The authors of the paper by Ajdacic-Gross et al. [3] investigate the monthly suicide frequencies for 6 possible methods. It turns out that for drowning and hanging there is a strong daylength-like seasonal pattern (see Table 2). Together these two means represent a weight of 65% of all the suicides in 1881–1920.

Now, let us for a moment assume that in the time interval 1969–2000 these means have been reduced to a small percentage of all suicides. As the other means exhibit weak seasonal amplitude, the reduction in hanging and drowning would be able to account for a substantial erosion of the total suicide pattern (as indeed observed). An explanation of that kind would constitute a progress in our understanding. Let us briefly explain why.

In the previous decomposition there are two different types of factors:

(1) The monthly profiles of the various suicide methods.
(2) The weight coefficients which describe the contributions of each method to global monthly suicide numbers.

The monthly profiles are difficult to measure because one needs a large number of suicides. How many? Let us assume that one wishes to distinguish between 10 methods and between males and females and that one wants at least 200 suicides in each month. This would require $200 \times 12 \times 10 \times 2 = 48\,000$ suicides. In the US there were some 30,000 suicides in 2001. In other words, even in a large country such as the US one needs to combine several years. This is of course even more necessary for smaller countries. Thus, the study for Switzerland required datasets combining some 40 years.

On the contrary, the weight coefficients can be measured annually without difficulty.

If the global seasonal patterns (in different times and countries) could be accounted for solely by plugging in the appropriate weight factors, that would mean that the monthly profiles for each method are more or less constant both in time and across countries. Such a finding would make the problem much simpler. It is in this direction that we wish to go.

Can the change in the weight coefficients explain the erosion in the global seasonal pattern? In 1969–2000 drowning and hanging still represented 41% of all suicides. The expected change due to the reduction from 65% to 41% (taking also into account the changes in the 4 other means) is given in Table 2; as can be seen, it is too small to account for the erosion of the seasonal pattern that actually occurred. This means that there has been changes in the monthly method profiles. Indeed,

Fig. 3 of Ref. [3] shows that there was a reduction in Spring and Summer suicides for hanging, drowning, firearms, cutting and jumping. These reductions account for the changes not accounted for by the weight factors.

Nonetheless, the previous decomposition has its usefulness.

- For the sake of simplicity we can restrict our attention to hanging and drowning. Why? Jumping, poisoning and cutting represent (in 1881–1920) small fractions of all suicides: 3%, 4%, 5% respectively which means that, whatever their specific shapes,[8] their contributions will be small anyway. Firearms suicide represents a more important fraction, namely 22%, but its monthly curve remains within a narrow band of ±10%. This band is three times more narrow than the one for drowning. In other words, at least in a first approximation one can forget 4 of the 6 classes.
- **Longitudinal analysis.** In terms of suicide methods, each country has its own traditions which one does not expect to change dramatically in the course of time. In the previous example of Switzerland the last two columns of Table 2 show overall stability. Few methods saw dramatic changes. One of the biggest changes was in the percentage of drowning which fell from 23% in 1881–1920 to 11% in 1969–2000 and to 5.9% in 2000–2004 [8].
- **Transversal analysis.** Precisely because each country has its own ways, there are big transversal differences in suicide methods. Thus, around 2000, in the US firearms and hanging accounted for 60% and 20% of all male suicides whereas in Germany these percentages were 10% and 55%. Based on this difference, one would expect a stronger monthly pattern in Germany than in the US. We will see in Fig. 4 that this is indeed the case.

4. Decomposition based on age-groups

A preliminary remark is in order to emphasize that it is essential to correct monthly suicide numbers by taking into account the length of each month. At first sight it might seem that a correction of $1/30 = 3\%$ is less than the statistical fluctuations of the data and it may therefore be considered as unnecessary.

However, that argument does not hold for two reasons.

- In February the correction is $(31 - 28)/30 = 10\%$. As month-to-month variations are usually less than 10%, most non-corrected series would display a spurious dip in February.
- The seesaw irregularities of uncorrected series will markedly reduce their correlation with smooth series such as daylength series.

4.1. Germany

Suicide statistics which give monthly data for different age-groups are available for several countries. We will mostly use German data because they give information for as many as 16 age-groups and cover several years between 2004 and 2011.[9]

Altogether the database includes some 80,000 suicides. Fig. 2 shows the monthly profile for 15 age-groups. In most of the age-groups the fluctuations in different years are sufficiently random so as to cancel out. Indeed, in many cases the average curve remains bounded within a narrow band limited by the two dotted lines. The cases in which the average breaks out of the ±10% strip are: 15–20 (negative deviation) and 65–90 (positive deviation). In other words, the daylength-like pattern is mostly a consequence of the suicide of elderly people over age 65.

4.2. Comparison between Germany and the US

On the website of the CDC-NVSS (Center for Diseases Control-National Vital Statistics System) one can download data[10] of suicide numbers per month for 5 different age-groups (males and females together). These data are available for 9 years (1999–2007). Altogether they include some 30,000 suicides annually[11] and 270,000 for the 9 years. Although the dataset is larger than the German dataset, it is less detailed in terms of age-groups.

The interesting fact is that these data lead to results which are fairly similar to those already described for Germany (Fig. 3), thus suggesting a validity that extends beyond the case of one specific country.

4.3. Comparison with Britain

Thanks to the help of the British "Office for National Statistics" we were able to analyze monthly suicide data by age-group. The results were in line with those obtained in the cases of Germany and the US.[12]

Age-group 15–24.9: $pl = 1.28$, $cor = -0.05$, $s = 0$
Age-group 25–64.9: $pl = 1.18$, $cor = 0.20$, $s = 0.38$
Age-group 65–84.9: $pl = 1.32$, $cor = 0.42$, $s = 0.73$

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[8] Their s indexes are low; for jumping which has the highest it is only 1.45.

[9] For some reason, the age-group > 90 is not given in 2005 and 2008. That is why (when we need all 8 years) we will limit ourselves to 15 age-groups.

[10] On 15 August 2014 the address was the following: http://www.cdc.gov/nchs/nvss/mortality/gmwk306.htm.

[11] This number implies that for a single month and a single age-group there are on average $30,000/(5 \times 12) = 500$ suicides.

[12] The data are for England, male+female, 1996–1998.
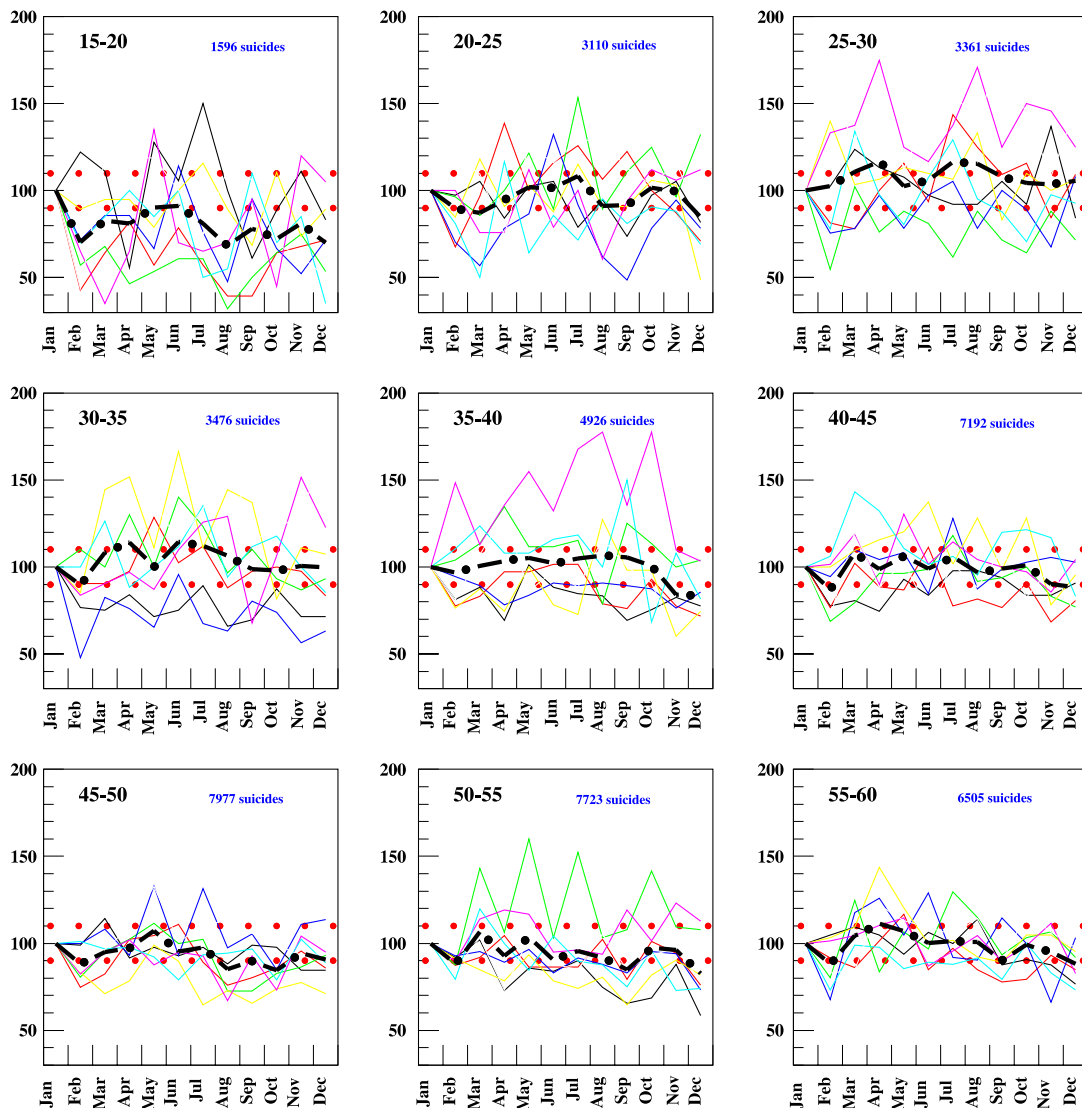
Fig. 2a. Suicides by age-group and month. In the text, each of these graphs was defined as being an *elementary monthly profile*. The age-groups include both males and females. On each graph there are 8 curves (in different colors) corresponding to the years 2004–2011. The thick dash–dot curve is the average over those 8 years. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Source: The data are from the German Federal Statistical Office, personal communication from Ms. Silvia Schelo.

4.4. Complementary observations

Naturally, one would like to know whether the regularities observed for German, US and British data also extend to other countries and other time intervals. In principle such data should be available in many countries, but they are not always made available to researchers or sometimes (as in France) at prohibitive cost. So far, we could find some complementary information in the following papers. By and large they confirmed our previous observations.

- McCleary and collaborators (1991) analyzed some 120,000 individual suicides which occurred in the US between 1973 and 1985. They focused particularly on two age-groups: H_1: men under 16 and H_2: men over 80. In spite of being restricted to very young and very old persons these age-groups experienced at least 600 suicides in any single month which means that their monthly profiles are reasonably reliable. H_1 shows a U-shape which goes below the horizontal line of the uniform distribution. In other words, it has a negative correlation with the daylength curve. On the contrary H_2 has a positive correlation and a P/L ratio equal to 1.20.
- The paper by McCleary et al. [10] was preceded by a paper by MacMahon [9]. Although it does not give monthly data by age-group, it is nevertheless of interest because it gives the monthly pattern in 1972–1978 that is to say some 30 years earlier than the 1999–2007 data represented in Fig. 3. Over this time interval of 27 years the amplitude of the curve has *not* been reduced: the peak/low ratio changed from 1.11 to 1.14. Moreover, because the second curve is more symmetrical
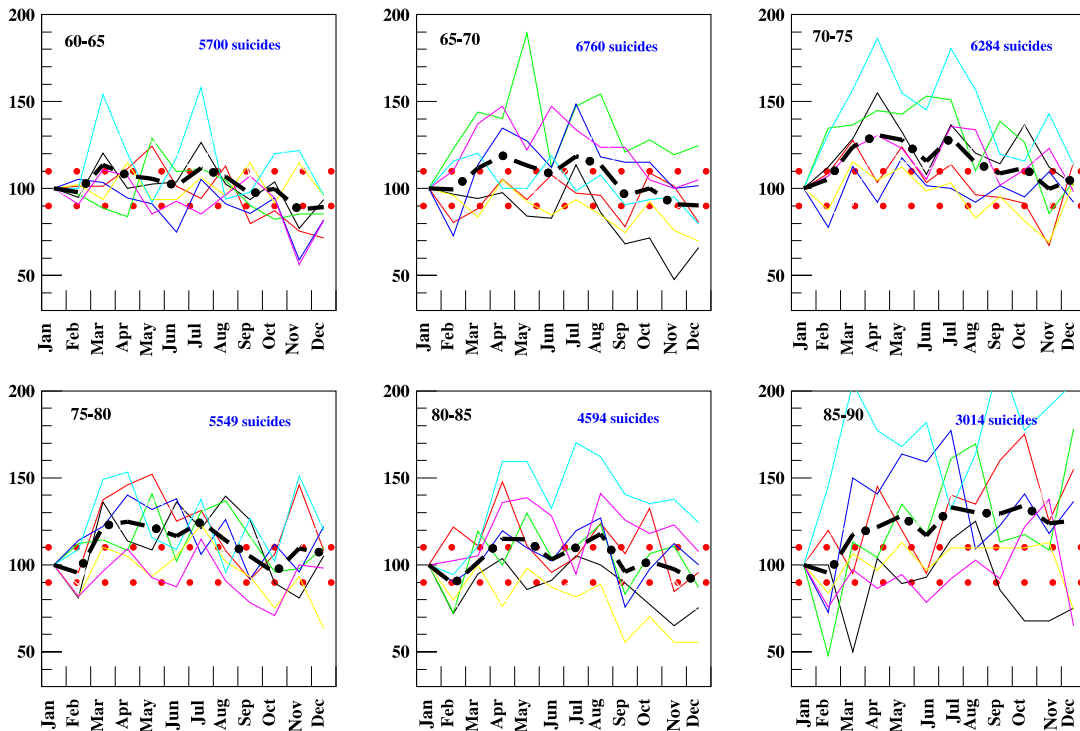
Fig. 2b. Suicides by age-group and month. There are only 6 age groups whose monthly profiles go beyond the ±10% band limited by the dotted lines, namely 15–20 and 65+ which comprise 5 age-groups. The large fluctuations seen on several of the graphs are due to small monthly numbers; for instance in the age-group 85–90 the average number of suicides per month is 3014/(12 × 8) = 31, had we taken only male suicides it would be even smaller.
Source: The data are from the German Federal Statistical Office, personal communication from Ms. Silvia Schelo.

with respect to the middle of the year, the correlation with the day-length curve markedly increased from 0.76 to 0.87. As a result, the seasonality index increased from 0.87 to 1.00.

- In Hakko et al. [11] some 21,000 suicides were analyzed that occurred in Finland during a 16-year study period 1980–1995. The authors considered only 3 age-groups, namely (i) under 40, (ii) 40–64 (iii) over 65.[13] They found that in the age-group 65+ the monthly suicide had a P/L ratio of 1.52.

4.5. Reconstruction of monthly profiles

In order to assess the validity of the simplifying scheme described at the end of the Section 3 about suicide methods , we will compute the weighted sum $s(m)$ when it is limited to selected age-groups (German data).

$$S(m) = \sum_{k=1}^{16} c_k f_k(m), \qquad s(m) = \sum_{k \in A} c_k f_k(m), \quad \text{One finds that: } S(m) \simeq s(m)$$

where

$$A = (15\text{–}24.9) \cup (65+) = \{1, 11, 12, 13, 14, 15, 16\}.$$

Here m denotes the month, k is the age-group index, the c_k are the weight factors defined as the suicide numbers in age-group k divided by the total number of suicides, A is the set of selected age-groups, i.e. (15–24.9) ∪ (65+), $f_k(m)$ is the monthly profile of age-group k.
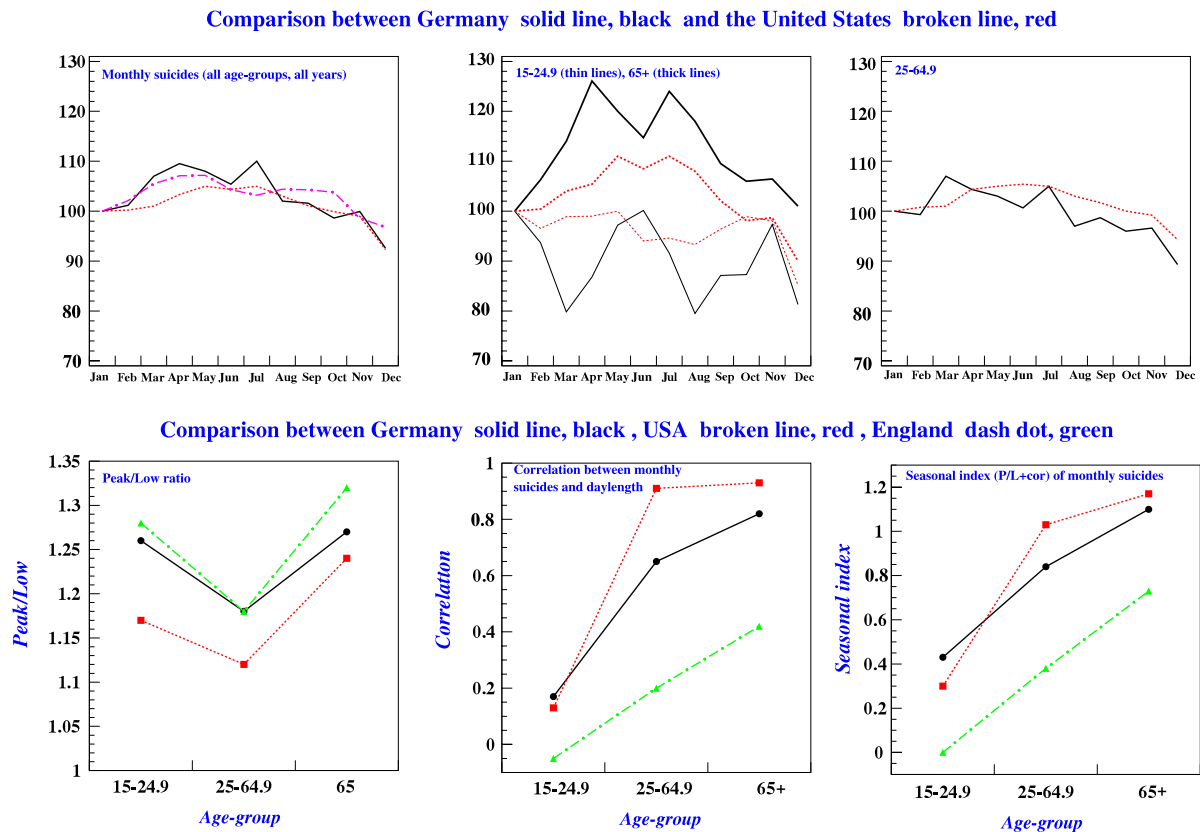
The exact monthly curve $E(m)$, the curve of $S(m)$ and the simplified reconstruction $s(m)$ are shown in Fig. 4.

Why is $S(m)$ not exactly equal to the exact monthly curve $E(m)$? It is because the c_k are based on the annual number of suicides; in fact, the monthly ratios have slight fluctuations with respect to this annual average.

The reconstruction method allows a simplification in a given time period. Yet, a more fundamental point concerns the stability (in time and across countries) of the elementary age-group profiles. This point will be tested in the following section.

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[13] Why did the authors restrict themselves to only 3 age-groups? The reason is simple. Suppose instead one takes 10 age-groups. Given that 80% of the suicides are committed by males that would mean that on average in each month and each age-group one would have (i) 21, 000 × (1/10) × (1/12) × 0.8 = 140 male suicides (ii) 21, 000 × (1/10) × (1/12) × 0.2 = 35 female suicides. Thus one ends with fairly low numbers of events in each bin. A rough rule of thumb is that one needs several hundred suicides in each monthly bin to keep statistical fluctuations at a "reasonable" level (say within ±20%).

Comparison between Germany solid line, black and the United States broken line, red

Comparison between Germany solid line, black , USA broken line, red , England dash dot, green

Fig. 3. Comparisons between Germany, the US and England. First panel: monthly suicides, all ages. The second panel shows the two extreme age-groups. The two lower curves show young age-group (15–24.9) while the top curves show the elderly age-group (65+). The third panel shows the middle age-group (25–64.9). In the graphs of the second line the horizontal axis shows the age of the three subgroups. Each curve corresponds to one country. Fourth panel: index P/L. Fifth panel: *cor* index. Sixth panel: Seasonal index s. These indexes are defined in the text. Whether in Germany (2004–2011), the US (1999–2007) or England (1996–1998), the young (15–24.9) and elderly (65+) age-groups show monthly profiles which diverge markedly from the fairly flat distribution of the middle-age group (25–64.9). In the first panel, for the sake of comparison, we have added the curve for the US in 1972–1978 (dot–dash curve in magenta color). For the sake of clarity the curves for England were not represented in the graphs of the first line but they are of similar shape. *Source:* The data for Germany are from the Federal Statistical Office. The US data are from the website of the National Vital Statistics System (GMWK306) and from the "Vital Statistics of the United States" annual volumes (1972–1978) as summarized in Ref. [9]. The data for England are from the UK Office of National Statistics; many thanks to Ms. Anita Brock.

5. Testing transversal predictions

Let us denote by $F_1(m)$, $F_2(m)$, $F_3(m)$ the three basic monthly profiles. If the monthly profiles by age-group (dash–dot curves in Figs. 2a and 2b) remain fairly stable from one case to another, the predictions given by the reconstructed monthly curves will be consistent with observation. If they are not, we can be sure that the age-group profiles are not the same in different countries. This would not be overly surprising. Let us recall that we have already seen a similar situation in our discussion of suicide methods. In this case the prediction (based on 1881–1920 profiles) for 1969–2000 did not agree with observation which revealed that the monthly profile changed in the course of time.

5.1. Procedure

Predictions of monthly patterns were obtained through the following procedure.

(1) The basic profiles $F_1(m)$, $F_2(m)$, $F_3(m)$ for the 3 age-groups[14] (15, 24.9), (25, 64.9), (65+) were defined by taking the average of the two cases for which we have good quality data, namely Germany and the US.
(2) For each country 3 weight factors c_k corresponding to the proportions of the suicides of the 3 age-groups with respect to the total number, namely:

$$c_1 = (15, 24.9)/\text{All}, \qquad c_2 = (25, 64.9)/\text{All}, \qquad c_3 = (65+)/\text{All}$$

were computed. For this purpose we used statistics from the World Health Organization (WHO).

14　Even though the middle-age component $F_2(m)$ is not expected to play a big role, we take it into account nonetheless.
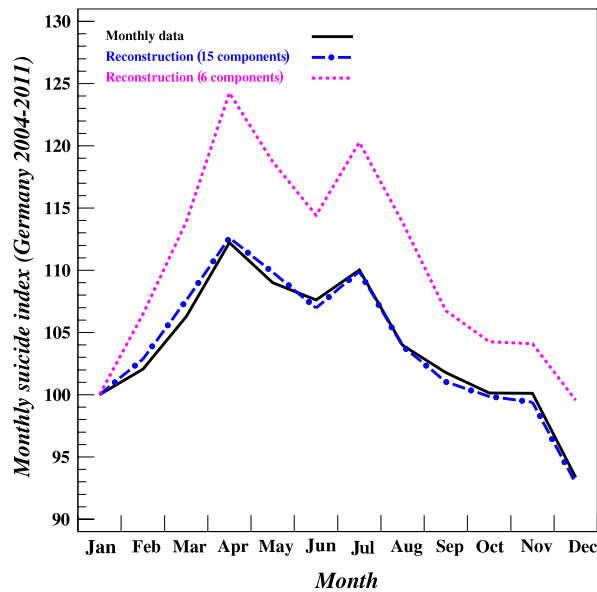
Fig. 4. Testing the reconstruction of the monthly curve with a reduced number of age-groups. We used only those age groups which contribute significantly to the monthly pattern, namely 15–20 and 65+ (5 age groups). The reconstructed curve $s(m)$ (magenta broken line) has the same shape as the exact curve $E(m)$ (black solid line); its parameters are: $P/L = 1.25$, $cor = 0.83$, $s = 1.08$ while the parameters of the exact curve are: $P/L = 1.19$, $cor = 0.80$, $s = 0.99$.
Source: The data are from the "German Federal Statistical Office".

(3) The 3 components were combined into a single monthly profile: $F(m) = \sum_{k=1}^{3} c_k F_k(m)$ which was then compared to the monthly profile actually observed.
(4) In order to estimate the discrepancy between predicted and observed profiles we computed their P/L and *cor* indicators. For each indicator the differences between predictions and observations were plotted (Fig. 5).

5.2. Results

South Korea, Spain and Turkey are characterized by high P/L amplitudes. Therefore it was expected that they could not be accounted for by combinations of profiles of cases of fairly low amplitude. However, at the correlation level the situation is quite the opposite. That was unexpected. A tentative explanation may go as follows. The correlation with daylight is well defined only when the profile has a clear ∩ or ∪ shape. When it is fairly flat even the smallest fluctuations will be able to completely change the correlation. Thus, the discrepancies seen for the low amplitude profiles of the countries in S2 may just be seen as fairly random fluctuations.

In conclusion, one can say that this test shows that South Korea, Spain and Turkey are characterized by elementary monthly age profile which are different from those of the other set of countries.

5.3. South Korea, Spain and Turkey

What makes South Korea, Spain and Turkey so different from the other cases and in fact similar to what was observed in European countries one century ago?
This is a key-question.
In order to throw some light on it one would need two kinds of data for these countries.

- Monthly suicide data for one century ago. The data would allow us to see whether or not there was a downward trend similar to what one observes in other industrialized countries.
- Present-day monthly suicide data by age groups. The data would allow us to see whether the amplitude for the (65+) age group is even higher than for the all-age profile.
  So far, unfortunately, we were unable to find such data. In the meanwhile one can tentatively propose the following explanation.
  The explanation relies on two separate effects.
- The first effect is the reduced seasonal effect in cities. This observation was already made by Durkheim [2]. He showed that the seasonal pattern was weaker in big cities than in the whole country.[15]

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[15] He gives evidence for Paris (1888–1892), Berlin (1882–1890), Frankfurt (1867–1875) and Vienna (1871–1872). Instead of considering monthly series he considered three-month averages corresponding to the four seasons: Winter (December–February), Spring (March–May), Summer (June–August), Fall
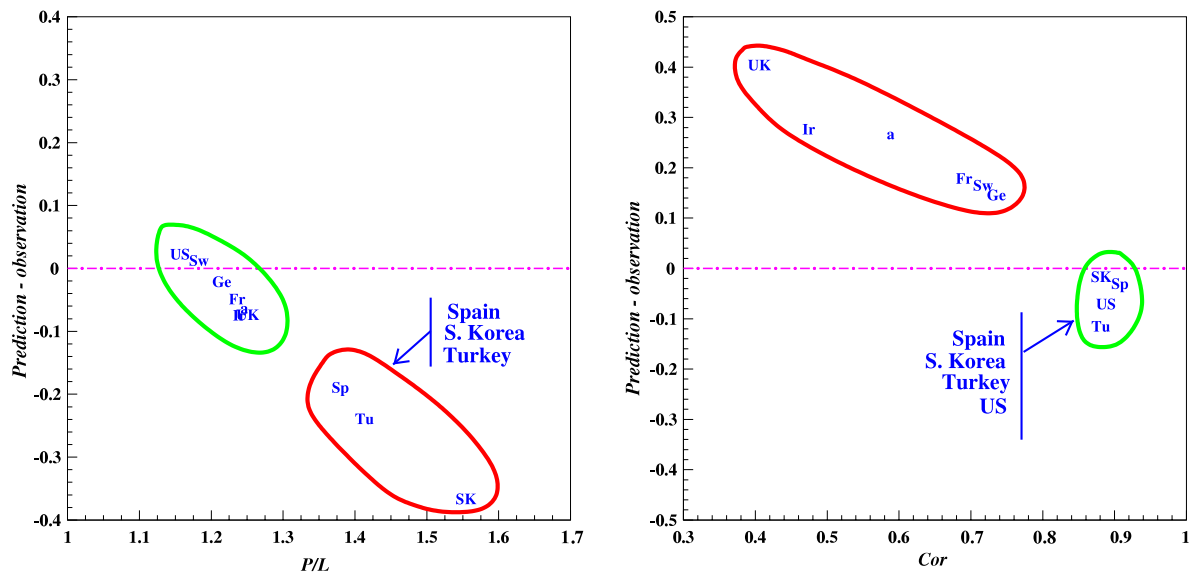
Fig. 5. Discrepancies between predictions and observations for 10 countries. Left-hand side: P/L, Right-hand side: *cor*. Clearly, there are two distinct clusters. (i) S1 = {South Korea, Spain, Turkey} (ii) S2 = {France, Germany, Ireland, Japan, Switzerland, UK}. The US is in the second subset for P/L and in the first for *cor* but in each case it is in fact close to zero.

- The second effect can be referred to as a *memory effect*. Observations show that persons who move from place A to place B will keep the suicide characteristics of A for a long time. Thus, people moving from Mexico to the US will keep the suicide rate of their country of origin for (at least) one or two generations. More generally, when immigrants moved from Europe to the US their suicide rates in the US were closely related with the suicide rates prevailing in their country of origin (see [4], pp. 217–220, the correlation was 0.77). Here, we will make the assumption that the same effect holds not only for the rate but also for the seasonal distribution.

The consequence of these two effects is that when people move from the country side (or from small cities) to big cities they will keep for some time the seasonal characteristics that they had before arriving to the big cities.

One characteristic shared by Spain, South Korea and Turkey is that they experienced rapid economic development and urbanization during the past decades.

Can this explanation be tested in some way? A place which experienced an economic development similar to the one in South Korea is the island of Taiwan. Thus, one would expect a similar seasonal suicide pattern. Is that the case?

To answer this question one must compare the P/L and *cor* of Taiwan to those of the two subsets in Fig. 4.

For Taiwan (2009–2013) one gets:

Taiwan: $P/L = 1.35$, $cor = 0.75$.

For Spain, South Korea and Turkey one gets[16]:

Sp, SK, Tu: $P/L = 1.43 \pm 0.09$, $cor = 0.88 \pm 0.01$.

For the 7 other countries, one gets:

Ge, US, UK, Fr, Ja, Ir, Sw : $P/L = 1.20 \pm 0.02$, $cor = 0.63 \pm 0.12$.

Through its P/L value Taiwan belongs to the same subset as Spain, South Korea and Turkey. The conclusion is less clear with respect to the *cor* variable, but we have already observed that the correlations in the subset of 7 countries are somewhat random.

Further tests will be possible as soon as reliable monthly suicide data become available for other countries which experienced a rapid increase in their urbanization rate.

6. What is the mechanism?

The main objective of the present paper is to focus on comparative analysis. That is why so far we did not wish to address the question of what is the underlying mechanism. However, in this concluding section we would like to discuss some possible mechanisms and particularly the one suggested by Durkheim [2].

(September–November). In all four cities the corresponding P/L was lower than in the whole country; the difference was 3% for Paris, 17% for Berlin, 20% for Hamburg and 23% for Vienna. The average of these 4 cases is 16%.

[16] The $\pm$ error bar refers to the confidence interval for a confidence level of 0.95.

6.1. Durkheim's conception of the phenomenon of suicide

In any system composed of individual elements there are two factors which control the ability of the elements to leave the system (or to remain inside).

- *Attraction forces* between the elements tend to prevent the elements from leaving the system.
- At the same time, the elements have their own independent incentives and impulses which, if strong enough, can lead them out of the system. For the sake of brevity we will call this effect the *noise factor*.

The great achievement of Durkheim was to show that this model is able to explain several key-properties observed in suicide statistics. It is important to realize that the drop-out rate, i.e. the suicide rate, is determined by the strength of the attraction forces *respective to* the strength of the noise factors.

The most important confirmation of Durkheim's model is provided by the fact that the suicide rate becomes higher when the strength of social links (and particularly family links) decreases. It is about 3–4 times higher for a bachelor than for a married man who has several children. In this case the effect relies on a change in the attraction forces whereas the noise factor can be supposed unchanged.

An opposite case is to keep the attraction forces unchanged and to raise the noise factor. It is on such a mechanism that Durkheim's explanation of the seasonal pattern relies.

6.2. Durkheim's explanation of the seasonal pattern

By analyzing the daily distribution of suicides over one week Durkheim observed that the number of suicides is lowest on Sunday and highest on Monday. This finding was confirmed by many subsequent studies. For instance, [9, p. 746] found that in the US between 1972 and 1978, Sunday had 3% less suicides than the weekly average whereas Monday had 8% more which corresponds to a P/L ratio of 1.11.[17] Based on his observation about daily suicides, Durkheim suggested the following mechanism.

- He made the assumption that the daily and monthly effects should be explained by the same mechanism. Although plausible, this assumption may or may not be true. At this point we do not know.[18]
- Because there is such an obvious contrast between Sunday and Monday in terms of economic activity, Durkheim concluded that this is the determining factor which explains seasonal and daily variations.

In short, Durkheim assumed that the noise factor is in proportion of economic activity. Assuming stable attraction forces, higher economic agitation will of course lead to more suicides. This gives a nice explanation of two of our previous observations. Because agricultural activity in the fields almost stops during the winter season that will result in a low suicide rate in December–January as is indeed observed. In big cities, most economic activities do not depend upon seasonal weather conditions, but a few do, as for instance activity in the construction sector. Thus, the seasonal pattern will be of smaller amplitude in big cities as seen above.

6.3. Objections to Durkheim's explanation

There are basically three objections.

- At first sight the most obvious objection would be the persistence of the seasonal pattern in highly urbanized countries like South Korea, Spain or Taiwan. However, if one accepts the time-lag explanation suggested above, this objection vanishes.
- In support of his explanation, Durkheim tried to define a statistical variable that can possibly measure "economic agitation". For that purpose, he used the number of accidents taken as a proxy of transportation activity, itself a proxy of economic activity. In the data that Durkheim presents for Italy (1886–1888) the maximum occurred in Summer and it was 17% higher than the yearly average. Durkheim was satisfied that this Summer maximum was fairly consistent with the Spring–Summer maximum of suicides.

  However, if one tries to repeat this test with present-day death data due to accidents one finds that there is no correlation between monthly accidents and monthly suicides. Just to take one example, in Taiwan (2012–2013), monthly accidents[19] have a correlation of -0.17 with monthly suicides. In 2012 the maximum of the accident series was in March and in 2013 in July but these maxima were fairly unclear in the sense that the series show fairly random fluctuations.

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[17] One may wonder how this rule is changed in countries in which the day of rest is not Sunday. Modan [12] reported that in Israel the number of suicides is highest on Sunday and lowest on Friday. However, this study is based on only 322 suicides (corresponding to 1962–1963) which means that for each weekday there were only $322/7 = 46$ suicides. That will give high fluctuations for the daily numbers.

[18] In support of Durkheim's hypothesis one can observe that according to our observations for the US in 1992 both the Sunday–Monday effect and the monthly effect are strongest in the age group over 65 and almost non-existent in the youngest age-group. However, in a paper by Ohtsu et al. [13] one learns that the Monday–Sunday ratio in Japan (2003) is 1.55 for persons aged 15–64 and 1.49 for the whole population (no data are given for the 65+ age group). This implies that the ratio for the population over 65 must be substantially smaller than 1.49. Such a result is therefore at variance with our observation concerning the US. Further investigations are required.

[19] Corresponding to the items V01-X59 + Y85-Y86 of the ICD10 classification of causes of death; these causes refer mostly to deaths in various forms of transportation, thus giving an appropriate measure of economic activity.

It can of course be argued that the number of accidents is not an appropriate measure of "economic agitation". This raises the question of how this agitation should be defined.

- Should one consider the fact that the seasonal effect is stronger for elderly persons than for middle-aged persons as an objection? Not necessarily. Elderly persons have usually weakened social ties.[20] This is consistent with the fact that in most countries suicide rates increase with age.

  Having weaker ties with their social environment, elderly persons are more affected by the noise factor. It is for the same reason that liquids with weak intermolecular attraction have high vapor equilibrium pressures and low boiling temperatures.

  What is less clear is why the monthly pattern of young people should be so different. Indeed, the social ties of persons between 15 and 19 seem weaker than the ties of middle-aged persons.[21]

  For the moment we have no explanation to offer for this apparent paradox. More comparative studies are needed before an explanation can emerge.

7. Conclusions

First we have shown that taken alone the rate of urbanization cannot explain the decay of the seasonal suicide pattern that one observes in industrialized countries over the past 150 years. South Korea, Spain, Taiwan and Turkey do not follow this rule. In order to throw new light on the question, we decomposed suicides into more homogeneous components. Following Ajdacic et al. [3] we first tried a decomposition according to methods of suicide. Second, we performed a decomposition into age-groups. The cases of Germany, the US and the UK (the only countries for which we were able to get monthly data by age-group) showed that the age-group decomposition leads to consistent results across countries. As a confirmation, it was shown that a reconstruction procedure gives acceptable predictions except for the four countries already mentioned.

Tentatively, we have proposed a time-lag memory effect to account for the survival of the seasonal suicide pattern in newly urbanized societies.

Finally, in an attempt to understand the mechanism responsible of the seasonal pattern, we have discussed the explanation proposed by Emile Durkheim. Coupled with the time-lag memory effect, it appears fairly satisfactory although further investigation is required to make clear the precise meaning of Durkheim's "agitation" variable. One also needs to understand the monthly suicide pattern of young persons.

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[20] Among the factors which may weaken social ties one can mention reduced mobility due to health problems, the death of the spouse, the fact that the children started their own family. However, admission into nursing homes or long-term care centers may increase the number of contacts. In order to determine to what extent the first effect will prevail will require a well–designed statistical inquiry.

[21] They are no longer really part of their parents' family and do not yet have their own family.