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Deciphering the fluctuations of high frequency birth rates

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HIGHLIGHTS

- New approach to analysis of impact of extreme events on birth data.
- Applied to influenza, heat waves and religious interdict of Lent.
- Data from 1650 to 2000 shows true impact of interdict on personal behaviour.

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ABSTRACT

Here the term "high frequency" refers to daily, weekly or monthly birth data. The fluctuations of daily birth numbers show a succession of spikes and dips which, at least at first sight, looks almost as random as white noise. However in recent times several studies were published, including by the present authors, which have given better insight into how birth is affected by exogenous factors. This paper demonstrates how it is possible to examine the adverse effects of catastrophes such as famines, diseases, earthquakes and heat waves on conceptions and link these to subsequent large anomalous troughs in the birth rate. Using both contemporary and historical data we also explore the changes over time which have taken place in birth rate troughs that arise from religious edicts within the Orthodox and Catholic populations in Romania and France respectively. These as well as other effects raise the hope that we will soon be able to "read" and interpret birth rate patterns in the same manner as for example Egyptologists may decipher hieroglyphs.

1. Introduction

That the determinants of conceptions and births are still not well understood is shown fairly clearly by the fact that measures taken to boost birth rates by governments of countries experiencing shrinking populations, e.g. Germany, Japan, Singapore or South Korea has proved largely ineffective. The fertility rates of these countries have been below 1.50 (that is to say more than 30% lower than the minimal reproduction level of 2.1) since 1995. Despite incentives introduced by the respective governments their fertility rate curves remain flat or decreasing. In 2015 the fertility rates in Singapore and South Korea were as low as 1.25.

Here, we do not focus on such long-term changes but on short- and medium-term changes. Nevertheless, some effects studied here may also have long-term implications. For example, consider the effect on births of religious interdicts. In the Middle Age in western Europe only about 70 days were left annually for permitted sexual relations. Had they been strictly followed, such rules would have drastically restricted fertility.

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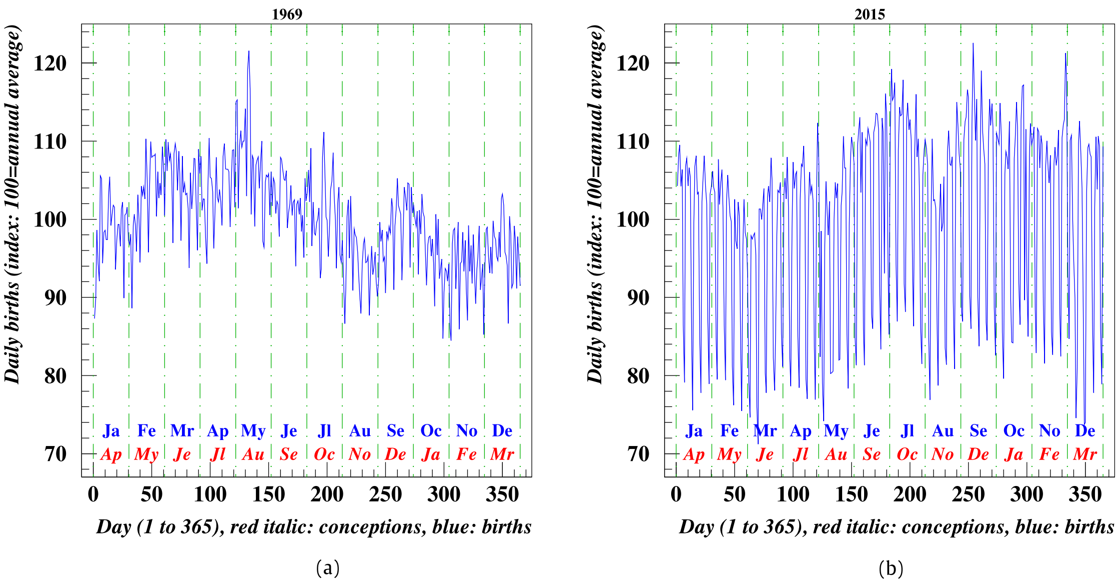

Fig. 1. a, b, Daily births in France in 1969 and 2015. The blue labels give calendar months whereas the red labels in italic indicate the corresponding conception months. Thus a conception in April would result in a birth in January of the following year. The same notation is used throughout the present paper. For the purpose of making relative variations more readable the series was normalized by making its average equal to 100. The substantial increase in dispersion has a simple explanation given below in the "Days off" section. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Source: Répartition quotidienne des naissances vivantes, France métropolitaine. Institut National de la Statistique et des Études Économiques (INSEE). [Daily distribution of live births. Overseas territories are excluded. National Institute for Statistics and Economic Studies]. Available on Internet under the title: "Les naissances en 2016. Tableaux de séries longues".

1.1. Seemingly random fluctuations

Fig. 1a,b represents daily birth numbers in France in 1969 and 2015. This fast succession of upward and downward spikes resembles a graphical representation of white noise except that instead of being stationary the signal displays also some medium-term fluctuations. From 1969 to 2015 there was a marked increase in the standard deviation that will be explained in a short moment.

1.2. Flawed tentative interpretations

To make sense of such a jerky graph seems a real challenge. Usually, the standard approach is to perform a moving window average which will eliminate high frequency changes. The remaining ups and downs are then interpreted in terms of specific human activities, e.g. vacation, harvesting in rural societies and so on which are assumed either to favor or reduce conception rates. Examples of such interpretations can be found in [1,2]. However, there is a fundamental flaw in this approach for one does not know the effect that vacationing and harvesting have on the sexual behavior of people. Any assumption made in this respect will be just wishful thinking. Take harvesting for example. In former rural societies it was a time of hard labor but also of celebration especially when the harvest was good. Which effect dominates?

1.3. Fact-driven methodology

We shall avoid such wishful thinking.[1] In fact, we take the problem by the other end. We start by identifying remarkable patterns. For example, discarding leap years, the average of daily births reveals huge dips. Then we connect such patterns with *sharply defined events*, for instance public holidays. In this way we can build a kind of dictionary of the connections between specific patterns and the events which triggered them.

[1] Incidentally, this is the advice already given by Emile Durkheim, one of the founding fathers of sociology, in his book "The rules of the sociological method" [3]. He suggested to investigate social behavior in the same way as one studies natural phenomena that is to say from "outside". Nowadays, his advice seems to be largely forgotten or overlooked.

1.4. Parallel with the deciphering of Egyptian hieroglyphs

The graphs of the time series of births can be seen as pictographs the meaning of which we try to discover. Pictographs were also used in the earliest forms of writing. More specifically, the challenge of the present research can be described through a parallel with the situation experienced in 1822 by Jean-François Champollion (1790–1832) after he was able to decipher the hieroglyphs displayed on the Rosetta Stone.[2] It gave him some clues in the form of phonetic signs and ideograms but it took several decades until a fairly comprehensive understanding of the language could be achieved. Our present situation is similar in the sense that we are able to explain a number of patterns which gives us some clues but many unsolved questions remain. For instance, later on we describe a new pattern that appeared around 2000 and for which we can at present only offer a tentative explanation. The deciphering of the Egyptian hieroglyphs was a long-term collective endeavor. Likewise we hope that the deciphering of the patterns of vital events (not only births but also deaths, marriages and divorces) will attract the attention of other researchers.

1.5. Outline of the paper

The paper proceeds through the following steps.

(1) First, we identify daily spikes attributable to holidays during which medically induced births are drastically reduced. In this way, all national holidays which occur on fixed days (such as 4 July in the US or 14 July in France) will become apparent. This is a fairly easy step which only requires an averaging procedure over a sufficiently large number of years.

(2) Secondly, we focus on adverse conditions which create troughs nine months later. This part builds on results obtained in a recent paper [4].

(3) The two previous parts give interpretations of dips and narrow troughs but not of wide troughs nor of peaks. Here we show that broad troughs can result from religious interdicts.

2. "Days off" effect

Fig. 2a shows the curve that one obtains by summing up 35 annual curves (restricted to non-leap years) such as those represented in Fig. 1a,b.

2.1. Reduction in the dispersion

Not surprisingly, the dispersion is reduced. Whereas the curve of Fig. 1a moves within 100 ± 10 the curve of Fig. 2 moves within 100 ± 5.

If successive years were independent their average would have a standard deviation 6 times (i.e. $\sqrt{35}$) smaller than the initial series. The fact that the dispersion is only divided by 2 shows that the successive annual series are correlated. Let us consider this point more closely.

The formula which gives the standard deviation of an average of n pair-wise correlated random variables $Y_n = (1/n)\Sigma X_i$ is: $\sigma(Y_n) = [\sigma/\sqrt{n}]\sqrt{1+(n-1)r}$ where σ is the standard deviation of the X_i and r their pair-wise correlation [5]. The special case $r = 1$ has a clear intuitive interpretation. A correlation of 1 means that all X_i are identical: $X_i \equiv X$, that is to say represented by the same time-series. Then $Y_n = X$ and $\sigma(Y_n) = \sigma$ which means that in this case averaging does not at all reduce the standard deviation. If, on the contrary, $r = 0$ one is in the well-known case of the average of independent variables which results in: $\sigma(Y_n) = \sigma/\sqrt{n}$.

Now, in the present case one has: $\sqrt{1+34r} = \sqrt{n}/[\sigma/\sigma(Y_n)] = 6/2 = 3$ which leads to $r = 0.24$. In words, the series are moderately correlated but nevertheless the fact that there are as many as 35 series results in a sizable effect on the standard deviation of the average.

2.2. Identification of the cause of the downward spikes

However, there are downward pointing spikes which reach well beyond this interval. From their positions it is easy to recognize that they correspond to fixed public holidays. The reduction in the number of births on non work days relates to medical induction of labor where drugs are used to induce labor in advance of it beginning naturally. Obviously such interventions will rather be planned on working days. In 2014 some 23% of American pregnant women experienced labor induction up from a percentage of 10% in 1990. Cesarean delivery has also increased: from 15% in 1996 to some 22% in 2011. Note that the figures for induced labor and Cesarean delivery should not be added together since the former may lead to the latter.[3] The proportion of induced delivery is about the same in France (Enquête nationale périnatale [Perinatal national survey] 2010).

For the period of 35 years following 1969 (excluding leap years) the average reduction in birth numbers for public holidays is about 12%.

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[2] See: https://en.wikipedia.org/wiki/Jean-Fran%C3%A7ois_Champollion.

[3] The sources are: "Quick facts about labor induction", August 2016; Centers for Disease Control: Recent declines in induction of labor by gestational age, June 2014.

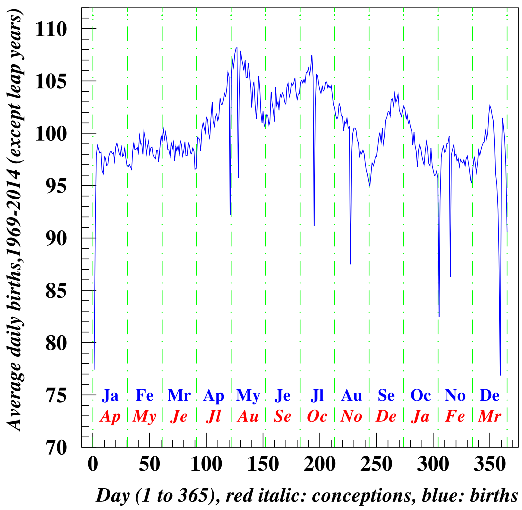

Fig. 2a. Average of daily births in France over 35 years, 1 January=1 The data cover 1969–2014 (leap years were excluded). The downward spikes correspond to non-mobile public holidays in France: 1 May is Labor Day, 8 May is end of World War I, 14 Jul is Bastille Day, 1 Nov is in memory of all deceased, 11 Nov is end of World War I, 24–25 Dec is Christmas. Source: Same as for Fig. 1.

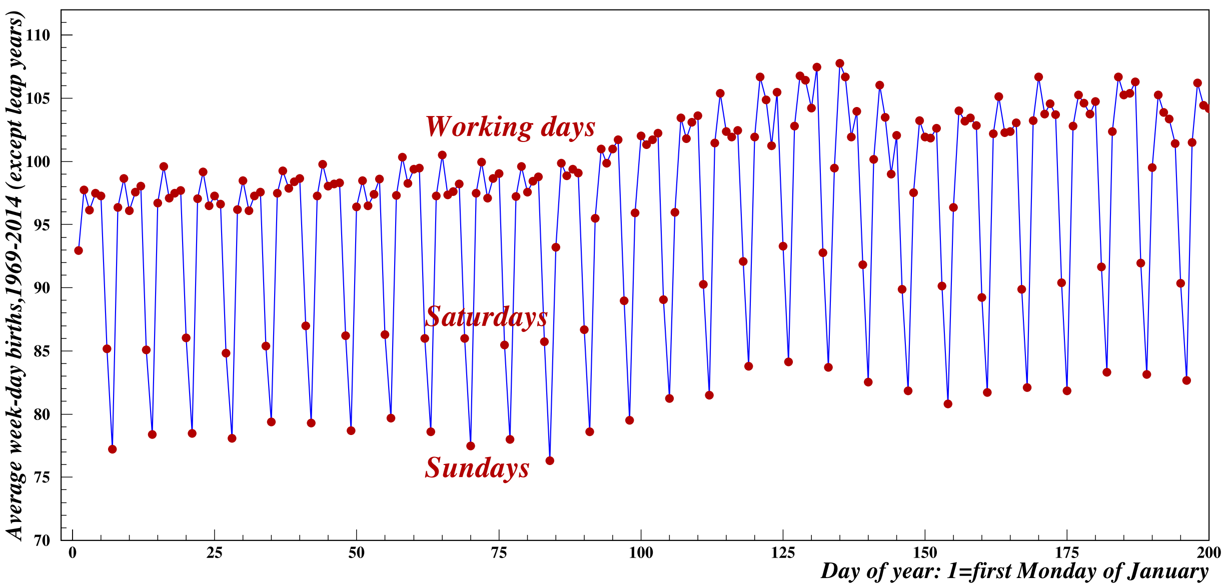

Fig. 2b. Average of daily births in France over 35 years starting with first Monday of January. The data cover 1969–2014 (leap years were excluded). The downward spikes correspond to Saturdays and Sundays. It is for the sake of clarity that the graph was limited to 200 days. The rest of the 52 weeks would not show any new effect. Source: Same as for Fig. 1.

2.3. Effect of Saturdays and Sundays

On Fig. 2a one cannot clearly see the effect of mobile public holidays. Examples are Easter or "Labor Day" in the US which is on the first Monday of September. For the same reason, the effect of Saturdays and Sundays does not appear. However, the weekends appear in Fig. 2b. Between Figs. 2a and 2b there is only a small difference in design but it makes a drastic difference in shape. In Fig. 2a, because the annual series start at 1 January which can be any day of the week the weekends are positioned fairly randomly with the result that in successive years the summation mixes weekends and working days. However in Fig. 2b the annual series start at the first Monday of January with the result that the weekends are at the same locations in successive years; thus, the summation singles them out in a clear way. By direct examination of the data, one finds the following reductions in birth numbers for 1969 and 2016 (Table 1).

The more induced Cesarean deliveries the deeper the dips in birth numbers on Saturday and Sunday.

Table 1
Saturday and Sunday reductions in birth numbers with respect to working days.
Source: Same as for Fig. 1. The topic of weekend birth rates is also studied and discussed in [6–8].

Year	Saturday	Sunday
1969	−1.2%	−6.8%
2016	−15%	−19%

Notes: The data are for France. The reduction indicated in the table refers to the difference between Saturday or Sunday and the average of adjacent working days.

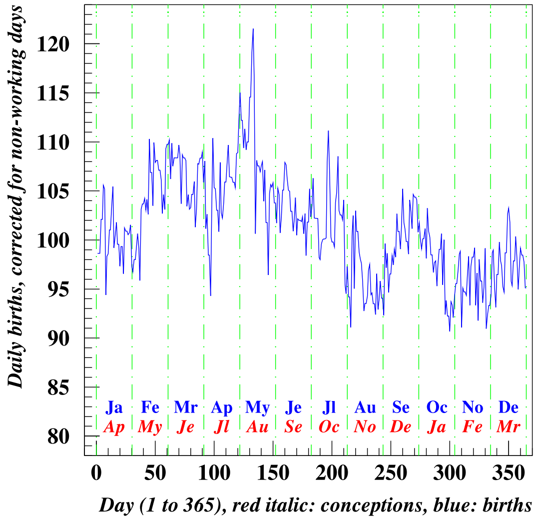

Fig. 3. Daily births in France in 1969 after anomalous non-working day data were smoothed out. Data for days off were replaced by the average of the births on the two adjacent working days. This resulted in a reduction of the standard deviation from 6.12 in Fig. 1 to 5.29 here. Source: Same as for Fig. 1.

2.4. Removal of the "Days off" effect

In order to estimate the global effect of days off on birth numbers, we replaced these data by the average of the births observed on adjacent working days. The resulting shape (see Fig. 3) is now much less jerky than in Fig. 1a.

The removal of the days off was performed in 3 steps. First, the public holiday births were replaced by the average of the nearest adjacent working days. Secondly, the Sunday births were replaced by the average of the corresponding Friday and Monday. Thirdly, the Saturday births were also replaced by the Friday–Monday averages. These substitutions led to the following reductions of the standard deviation.

$$\text{Initial: } \sigma_1 = 6.1, \text{ No public holidays: } \sigma_2 = 6.0, \text{ No Sundays: } \sigma_3 = 5.4, \text{ No Saturdays: } \sigma_4 = 5.3$$

3. Effect of adverse living conditions on conceptions

The removal of the "Days off" effect has a dramatic impact on the shape of the curve of daily births, but it is a fairly obvious effect. Less trivial is the effect resulting from adverse living conditions which can be revealed through a surge in mortality. This effect is less obvious for two reasons.

• It occurs at time of conception that is 9 months before the births.

• From conception to birth there are several successive steps which involve social as well as biological phenomena. It is through a comparative examination of several case studies that the key role of social as opposed to biological factors was revealed [4,5].

In this section, this effect will be examined using two cases.

(1) The impact of influenza outbreaks on conceptions.

(2) The impact of heat waves on conceptions.

3.1. Effect of influenza on January births

In [4] the authors used data for influenza outbreaks of exceptional gravity such as in 1889 or 1918. Here we consider "ordinary" outbreaks of the kind that occur every year either in December or (most often) in January. Naturally, the effect is less spectacular but this analysis will show that even small outbreaks have a sizable effect on conceptions.

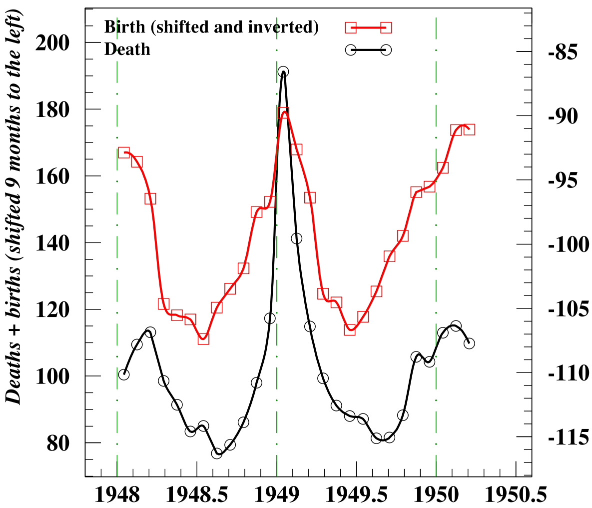

Fig. 4a. The effect on births of an influenza outbreak in France in January 1949. There are influenza outbreaks every year but the one of January 1949 was particularly severe which is why it was selected. The birth series has been moved 9 months to the left so that it represents conceptions rather than births; moreover it has been inverted so that the birth trough appears as a peak. This kind of representation was introduced in [4].
Source: Births: Same website as for Fig. 1. Deaths: "Nombre moyen de décès par jour selon le mois depuis 1946 pour la France métropolitaine", INSEE. [Monthly numbers of deaths divided by the length of each month from 1946 to 2016]. Available on Internet under the title: "Les décès en 2016. Tableaux de séries longues".

Our strategy is to select years which have the highest January death rates. In this respect it is important to observe that there is a high degree of correlation between January death rates either for influenza or for all causes of deaths.

For instance, in the United States for 18 years from 1999 to 2016 the correlation is as high as 0.82. This is a remarkable result for influenza and pneumonia (code J09-18 of the International Classification of Diseases) deaths in fact represent only a small fraction (about 3%) of the total deaths of January. Despite this small fraction influenza nevertheless controls the January deaths because, apart from influenza changes, the total January deaths are very stable having a coefficient of variation of only about 5%. Thanks to the high correlation, we can select the appropriate years by using either the monthly influenza deaths or, in the countries where such data are not available, the monthly total deaths.

3.2. The "death–nobirth" effect

Fig. 4a shows that the death peak of January 1949 (which is the largest in the whole time period) has an amplitude peak/average of 1.8; this can be read easily on the graph because the curve was normalized so that the average corresponds to an index value of 100.

In order to facilitate the comparison between the death and birth curves, the latter was moved 9 months to the left (which in fact transforms it into a conception curve) and inverted through a change in its sign. The scale on the left-hand side shows that the amplitude of the birth curve is only 1.1. As shown in [4], this is a general property: whether the mortality is due to influenza, food scarcity or earthquakes, the amplitude of the birth trough is always smaller than the amplitude of the death peak.

For the sake of brevity, the present effect will be called the *death–nobirth* effect.

3.3. Relationship between the amplitudes of death peaks and birth troughs

In the previous subsection we considered a single, fairly spectacular, case. However in order to find out the relationship between the death peaks and the ensuing birth troughs we need to select and analyze a whole set of cases. First of all we explain how these cases should be selected.

For low January death rates, the impact on births will be masked by the background noise. In other words, in such cases the effect may still exist but it will not be visible. In Fig. 4b we selected the years in the interval 1949–1974 for which the January deaths were higher than the annual average.

Why limit ourselves to the interval 1949–1974? At the end of this section we show (in Fig. 7b) that toward the end of the century a new effect appeared which created secondary troughs some 2 or 3 months after October. Although the influenza troughs are still present the secondary troughs complicate the picture. By limiting ourselves to 1947–1974 we avoid this difficulty.

In [5] the analysis of the massive influenza deaths which occurred in the US in 1918 led to the following relationship between the amplitudes A_d of death peaks (defined as peak value/average) and the amplitudes A_b of birth troughs (defined

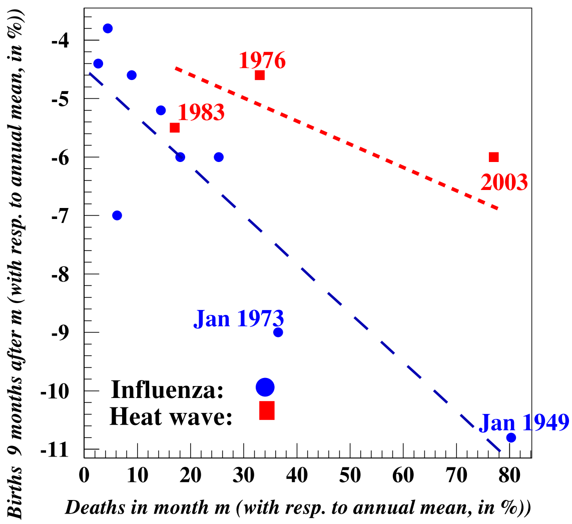

Fig. 4b. The effect on births of influenza outbreaks in France between 1948 and 1974. Relationship between monthly excess deaths in January (with respect to the annual average and reduction in births in October of the same year. The coefficient of correlation is −0.89 and the equation of the regression line is given in the text. The three squares in red correspond to heat waves in France (see the text). Sources: Births: Same website as for Fig. 1. Deaths: "Nombre moyen de décès par jour selon le mois depuis 1946 pour la France métropolitaine", INSEE. [Monthly numbers of deaths divided by the length of each month from 1946 to 2016]. Available on Internet under the title: "Les décès en 2016. Tableaux de séries longues". Effect of heat waves:

as average/trough value): $A_b \sim A_d^\alpha$, $\alpha = 0.19 \pm 0.1$ For the data shown in Fig. 4b a similar calculation leads to[4]: $A_b \sim A_d^\alpha$, $\alpha = 0.12 \pm 0.04$

The fact that similar exponents are obtained in fairly different conditions shows that these relationships are fairly robust. In what respect are the conditions different? First, the countries are not the same. Secondly, as already observed, the US data are for exceptional massive mortality numbers whereas the French data are for "normal" influenza mortality. Thirdly, the US data are for different states in the same year (1918) whereas the French data are for the whole country in different years.

3.4. Effect of heat waves on death rates

It seems common sense that heat waves may affect fragile persons particularly babies and elderly people. Naturally, one would expect this effect to be more pronounced in countries (such as France or Switzerland considered below) where air conditioning is not common. Although there have been many papers which document this effect only few give age-specific results. Among the latter, two fairly recent papers are particularly noteworthy in this respect, namely Rey et al. [9] for France and Vicedo-Cabrera et al. [10] for Switzerland.

For the present investigation it is particularly important to know which age groups are most affected since, if only babies and elderly are affected, there will be no reduction in births 9 months later. Fortunately, the paper by Rey et al. [9] has a table which gives all the information that we need (see Table 2).

Table 2 shows that, not surprisingly, young people under 35 are under-represented among heat wave victims while elderly people over 75 are over-represented. However, the same table shows that for influenza the proportions are almost the same. Actually, we are not interested in the persons who die but rather in those who are affected and survive. Thus, the real question is: "Are influenza survivors more affected than heat wave survivors?" By studying the effect on births, we can answer this question at least for the specific meaning of "being affected in terms of conception capacity". In the next subsection we will see that influenza affects surviving people more seriously than heat waves do.

3.5. How conceptions are affected by heat waves

Whereas many papers have considered the effect of heat waves on death rates, to our best knowledge only one author has investigated the effects on birth rates nine months later. In a pioneering study Régnier-Loilier [11] analyzed the effect on conceptions and births of 3 of the 6 heat waves that occurred in France, namely: 1976, 1983 and 2003. Here the percentages of deaths with respect to annual deaths are of the order of a few percent that is about 10 times smaller than for influenza deaths. This makes the analysis more tricky. In order to remove the seasonal fluctuations Régnier-Loilier divided the births of the year under consideration by the average of the series of the two adjacent years. This leads to the identification of birth troughs whose width is about 40 days.

4 The error bars are for a confidence level of 0.95.

Table 2
Age distribution of the victims of heat waves and influenza respectively.
Source: Heat waves: Rey et al. [9, Table 1]. Influenza: CDC-Wonder database.

	All ages 0–100	All ages 0–100 (per million pop)	Age 0–35	Age 35–75	Age 75–100
France (population=60 million)					
Deaths during heat waves, 1975–2003 (1)	4,400	73	3.5%	24%	70%
Deaths in normal conditions, 1975–2010 (2)			8.0%	37%	54%
Excess mortality ratio (1)/(2)			0.33	0.65	1.30
US (population=300 million)					
Deaths from influenza, 1999–2016 (1)	57,700	192	1.8%	23%	75%
Deaths in normal conditions, 1999–2016 (2)			4.5%	39%	56%
Excess mortality ratio (1)/(2)			0.40	0.59	1.34

Notes: The heat wave data are for France and are an average of 6 heat waves, namely: 1975, 1976, 1983, 1990, 2001, 2003. The influenza data are for the United States and are an average for 1999–2016. For a same population there are about 2.6 times more influenza deaths than heat wave deaths. Moreover, contrary to influenza outbreaks which basically occur every year, heat waves take place on average only every 5 years.

Such shocks belong to the same death–nobirth category as those for famine, influenza or earthquakes considered above. That is why it makes sense to plot the results in the graph of Fig. 4b. We can see that for the same percentage of deaths one gets smaller conception troughs. This provides an answer to the question raised above. It turns out that for the same number of fatalities the heat wave survivors are less affected than the influenza survivors, intuitively a rather natural conclusion. This statement is a description in words of the fact that the data points for the heat waves are above the data points of influenza. As the *y*-axis has a negative scale, "above" means a smaller birth troughs.

We conclude the discussion of the effect of heat waves on conceptions by explaining in more detail the calculation procedure used in [11].

3.6. Identification of the birth troughs due to heat waves in France

Between 1975 and 2005 there were 6 heat waves but the one of 2003 was by far the most severe. In this case there is absolutely no doubt about its effect on conceptions; this effect appears clearly in Fig. 7b.

In the other 5 cases the heat wave was much weaker. As a result, the birth troughs do not appear on the monthly data. Régnier-Loilier [11] used daily birth data. Due to the large daily fluctuations (illustrated at the beginning of this paper), the expected birth trough are hidden by the background noise. To make them visible the following operations were performed.

- First, each annual birth series b was "renormalized" through division by the average of the two adjacent birth numbers, e.g. $b = (1977)$ was replaced by $b' = 1977/[(1976 + 1978)/2]$. This is a fairly common way to smooth the series and reduce variability. However that is not what is observed here: in the three cases of 1977, 1984, 2004 the coefficient of variation (CV) of the initial series is smaller than the CV of the renormalized series; for the three cases the ratio is on average 0.97,
- As the series are still fairly bumpy further smoothing is performed via a moving average with a window width of 21 days. These operations lead to series which have more ups and downs than the initial series but which also display birth troughs nearly where expected. In short, the effect may well exist but due to its small magnitude it is at the limit of being detectable.

It is natural to test if, as in Fig. 4b, there is a correlation between death peaks and birth troughs. As such a test would be meaningless with only 3 cases, we repeated the calculation done in [11] and extended it to the three other heat waves. However, it turns out that no correlation could be detected. One should perhaps not be surprised for a sample of only 6 cases can hardly provide a clear answer unless the correlation is fairly high which is not expected here.

3.7. Removal of the death–nobirth effect for daily births

To what extent are the fluctuations of births shown in Fig. 3 reduced when the death–nobirth effect is removed, that is to say when the dips due to excess-deaths 9 months earlier are compensated for. This compensation process is made by using the linear regression equation for the data of Fig. 4b. The standard deviation is reduced from the previous value of $\sigma_4 = 5.3$ to $\sigma_5 = 4.7$ (a reduction of 11%). This is a fairly small reduction and Fig. 5 explains why it is not larger.

In order to affect the births of 1969, the deaths must occur in the time interval shown in magenta in Fig. 5[5]; within the two years 1968–1969 this defines a specific time interval. In this interval there are only small sub-intervals (marked in red) which have excess-deaths. Therefore the curve of the births during 1969 is only slightly changed. Despite this small impact the standard deviation of births is nevertheless reduced by 11% showing that the correction works in the expected way, namely by pushing up the troughs. The modified birth curve is omitted because visually the changes are rather subdued.

[5] More precisely we have taken a pregnancy duration of 267 days as explained in [4].

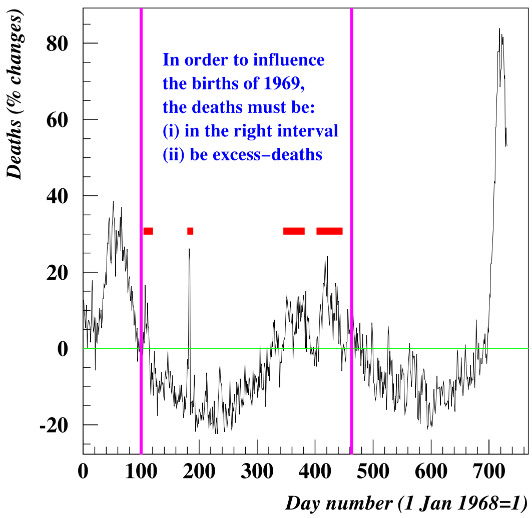

Fig. 5. Removal of the death–nobirth effect, for daily births, France 1968–1969. This figure explains why in 1969 the removal of the death–nobirth effect has only a small incidence.Sources: Same website as for Fig. 4. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

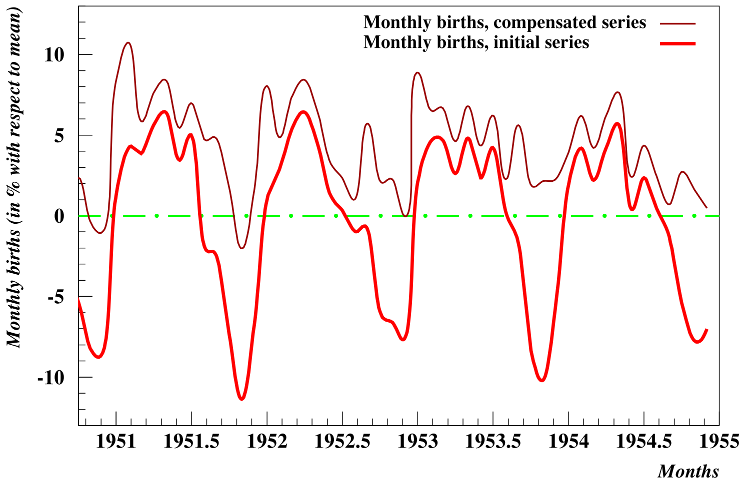

Fig. 6. Removal of the death–nobirth effect, France 1950–1954. For the compensation we used the regression coefficients a, b obtained in Fig. 4b; then the compensation was done as follows: $\Delta b = a\Delta d + b$, where Δd, Δb are the excess deaths and excess births respectively; then $b_c = b_i + \Delta b$ where b_i, b_c are the initial and compensated birth series respectively. Note that this compensation was done only when there were excess deaths, that is to say when the death series was above its average. In the graph, the compensated series was translated upward by 2% to avoid a superposition with the initial series in all intervals in which there is no compensation. Sources: Same website as for Fig. 4.

3.8. Removal of the death–nobirth effect for monthly births

Graphically the effect of the removal of the death–nobirth effect becomes clearer at the level of monthly births, as shown in Fig. 6. It can be seen that all deep troughs occurring around September are replaced by fairly shallow troughs. This corresponds to a reduction of the standard deviation from 5.11 for the initial series to 2.90 for the compensated series.

The previous procedure was quite successful but now we must try to explain unexpected birth troughs which appeared in recent decades (see Fig. 7b).

3.9. Beyond the death–nobirth effect

Before coming to the "new" birth troughs we show in Fig. 7a a decade where they are well accounted for by the death–nobirth effect.

In Fig. 7b the birth troughs follow a different pattern which displays the following features.

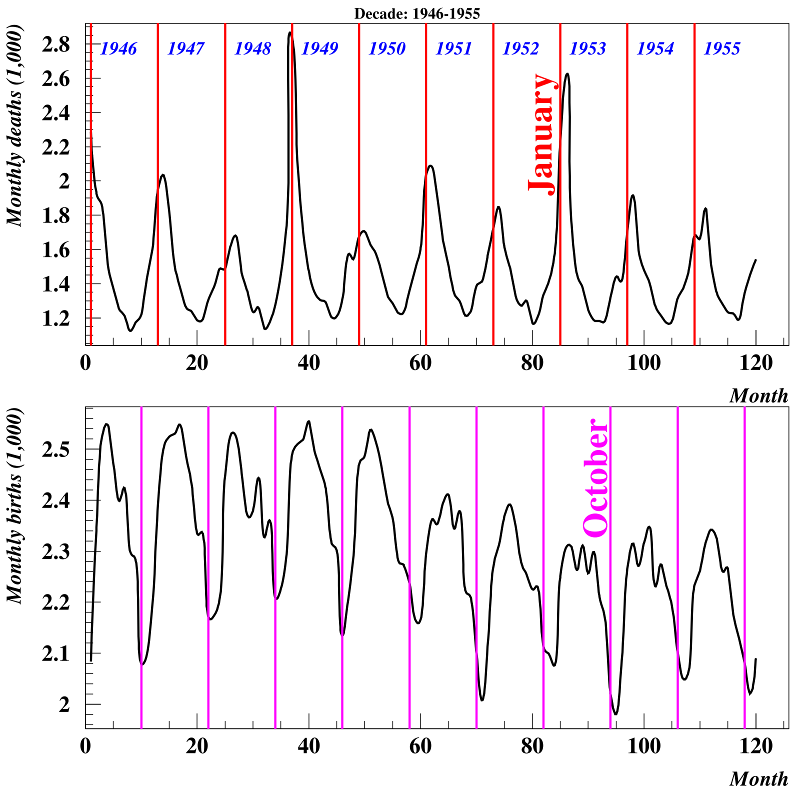

Fig. 7a. Illustration of the death–nobirth effect. The data are for France and correspond to monthly deaths and births divided by the number of days of each month. All red lines of the death graph indicate January and all magenta lines of the birth graph indicate October (i.e. January+9months). It can be seen that the birth troughs follow the death spikes with the expected time lag of 9 months. However, as shown in the next figure, in the decades after 1990 the birth pattern becomes more complicated.Source: Same website as for Fig. 4. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

• The death peaks are still in January (indicated by the vertical lines in red) with the only exception of the heat wave of the summer of 2003.

• Except in 1997 and 1999 he birth troughs are no longer in October (indicated by the vertical lines in magenta) but rather in December.

• Between the birth peaks and the birth troughs there is nearly a 9 month interval.

• The death–nobirth effect did not really disappear but the October dips are shadowed by the presence of lower dips. What can be the origin of the new troughs?

By comparison with Fig. 7a the births dips appear more disorderly; for instance often they display double dips. Similarly the birth peaks appear also more disorderly in the sense of a single spike there are often double spikes. In other words, there seems to be a connection between birth spikes and birth dips. This observation leads to a possible explanation.

It is self evident that for a couple, conception at time t excludes conception during the following 9 months. If *all* couples (of child bearing age) would conceive in October, then during the subsequent 9 months there would not be a single conception. As a result, one would see a huge birth peak in October + 9 months=July, followed by a 9-month interval without any birth. In the real world where couples are not highly synchronized one may expect a conception peak to be followed by a conception trough during the following nine months. For the sake of brevity this effect will be referred to as the *single conception* effect. Needless to say, as it is a basic biological effect the single conception effect will always be present. However, it will be clearly visible only when the birth peaks are high and fairly narrow. With broad and rather low birth peaks the effect will be “diluted” and hardly visible.

If our assumptions are correct the birth pattern will be a superposition of two effects: the death–nobirth effect and the single conception effect but the weight of each effect may change in the course of time. When the January influenza death spike becomes lower as a result of more persons being vaccinated, then the weight of the death–nobirth effect will dwindle and, as a result, the single conception effect will become more apparent.

We conjecture this is what happens here. From the 1950s to the 1990s the average amplitude of the January death spikes decreases from 1.5 to 1.15 and as a result the death–nobirth effect is eclipsed by the single conception effect. This explanation should be tested more thoroughly in a subsequent paper.

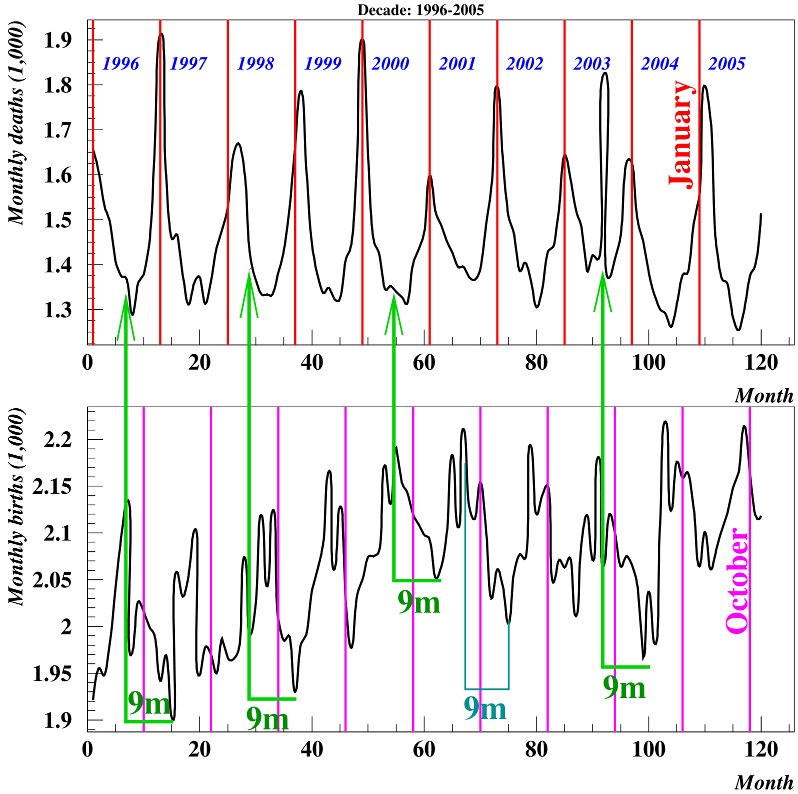

Fig. 7b. Apparition of a new effect which produces birth troughs not related to death spikes. Here, in most of the cases the time lags between death spikes and birth troughs are longer than 9 months. However the death spike associated with the heat wave of August 2003 is followed by a birth trough 9 months later (i.e. in May 2004). In addition, we observe a time lag close to 9 months between birth peaks and birth troughs (see the U shaped line in cyan) for which an explanation is suggested in the text.Source: Same website as for Fig. 4. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Influence of the religious environment on conceptions

Some religious precepts rule out sexual intercourse during special periods. For instance, during the month of Ramadan, sexual activity is not allowed during the day but is permitted during the night. The Orthodox religion advises against sexual activity during Lent which in Orthodox countries is the 7-week period (49 days) preceding Easter.

In present day Catholic and protestant religions there are no specific precepts on this point. However, although the scriptures do not say anything in this respect in past centuries the Catholic Church prohibited sexual activity not only during Lent (46 days before Easter) but also in many other periods, e.g. 40 days before Christmas, 40 days after giving birth, or on all the nights from Saturday to Sunday.

Conversely, on some specific days, sexual intercourse is encouraged. This is the case for Saturday (or more precisely Shabbat which starts already on Friday night) in the Jewish religion.

With respect to birth rates this leads to the following questions.

(1) Is there empirical evidence showing that some religious precepts affect the pattern of births?

(2) Is it possible to document the impact of religious rules over the course of time and across countries?

4.1. Empirical evidence: the Fire Horse years in Japan

An easy way to show the impact of beliefs on births may be found in Japan. No monthly or daily data are requested, annual birth data are sufficient (see Fig. 8).

The number of people (both males and females) born in 1966 is much smaller than in 1965 or in 1967. The difference is of the order of 25%. It turns out that 1966 was a Hinoeuma year, which means a Fire Horse year in the Chinese calendar.[6] According to popular belief in Japan girls born in that year grow up to be "Fire Horse women" who are reputed to be

[6] Because the Chinese New Year occurs in late January, the Fire Horse Year does not exactly coincide with 1966; in fact, it started on 21 January 1966 and ended on 8 February 1967.

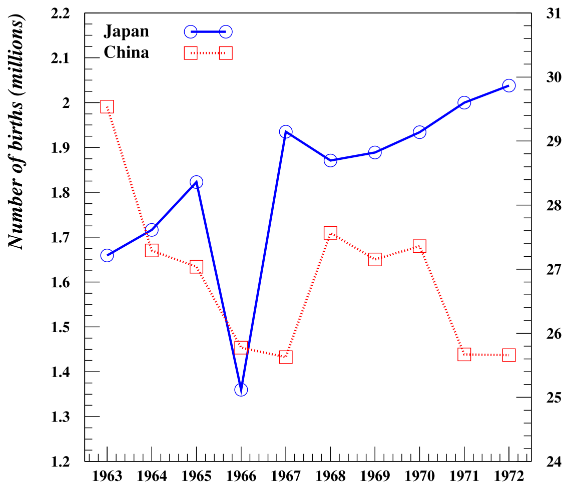

Fig. 8. Annual number of births in China and Japan. The sharp reduction of births in Japan in 1966 can be related to the fact that in the Chinese astrological calendar it was a "Fire Horse" year. In Japan there is a kind of prejudice with respect to girls born in a Fire Horse year. The fact that this belief exists in Japan but not in China suggests that it has little to do with Buddhism but is rather a local tradition.
Source: Japan: Historical Statistics of Japan. China: [12, p. 268].

Table 3
Birth reductions in the last three Fire Horse years in Japan.

	1846	1906	1966
Fall in annual births (%)	−11%	−11%	−24%

Notes: The percentages refer to the differences between the year under consideration and the mean of the 9 other years in the same decade. The high reduction in 1966 is due to two factors. (i) Contrary to what happened in 1846 and 1906, in 1966 the male–female sex ratio at birth increased only by 1.3% instead of 20% in 1846 and 4.3% in 1906; this means almost no infanticide in 1966. (ii) In 1946 there was a sharp fall in births which generated a small cohort; then, in 1966 this cohort reached the age of 20 at which point it started to have children.

headstrong and to bring bad luck to their families. In 1966, as a baby's sex could not be reliably identified before birth, there was a sharp fall in birth rate, partly due to a fall in conceptions and partly to an increase in abortions. According to the Chinese calendar, Fire Horse years occur every 60 years; thus, the three previous ones were in 1906, 1846 and 1786. Are the effects in those years similar to the one in 1966? For 1786 there are no data but for the three subsequent years the answers are given in Table 3.

Was there was a similar effect in China? In spite of the fact that 1966 has less births than adjacent years, there is no sudden drop, which means that the trough around 1966 may be due to other reasons. Note also that in Japan 1966 had a larger male/female birth ratio than adjacent years; the jump from 1.053 to 1.076 may seem small but is significant because in normal years the male/female ratio is very stable. In China the male/female ratio does not show any special behavior in 1966. [7]

4.2. Empirical evidence: the case of Lent in Romania

There are two good reasons for examining the case of Romania.

• As mentioned above, in contrast with the Catholic or Protestant religions, the Orthodox religion has clearly defined rules regarding sexual relations during Lent. In the census of 2011, 86% of the Romanian population identified as part of the Eastern Orthodox Church.

• Because the time of Lent changes from year to year it is a much better "marker" than a fixed religious day. Although a single observation may display a reduction in births it will not reveal the reason of the reduction. In contrast, if in successive years the birth reductions follow closely the Lent time-intervals, then there can be little doubt that Lent is the causal factor.

The effect of religious rules on conception during Lent was investigated in [13]. For such a study one of the main difficulties is the fact that strictly speaking monthly birth data are not detailed enough to follow the shifts of Lent. One needs weekly or daily data. Fortunately, the Romanian Bureau of the Census asked all persons surveyed in the censuses of 1992 and 2002 for their birth day dates.

As some elderly persons may not remember their birthday with absolute accuracy, in order to limit this uncertainty the dataset was limited to the persons born after 1905; thus, those were less than 87 year old in 1992. Because the size of a

[7] Although a Hong Kong–Canadian movie produced in 2005 and entitled "Eve and the Fire Horse" suggests that in 1975 the "Fire Horse" belief was still present in China, this view was *not* confirmed by discussions with Chinese colleagues; as a matter of fact, they had no knowledge of it.

Table 4
Conception reduction during Lent, 1931–1935.
Source: Bunle [14, p. 92–93].

Conceptions in:	Feb.(f)	Mar. (m)	Apr. (a)	R=m/[(f+a)/2]
Bulgaria	891	688	983	0.73
Romania	911	686	919	0.75
France	985	930	1042	0.95
Spain	911	947	1096	0.94
Norway	857	899	992	0.97
Sweden	904	941	979	1.00

Notes: *R* equal to 1 would mean that March which represents Lent has same conceptions as the two adjacent months that is to say no reduction due to Lent. The monthly numbers given in the table are an index which sums up to 1,000 for one year. Bulgaria and Romania are Orthodox countries, France and Spain are Catholic countries, Norway and Sweden are Protestant countries.

cohort decreases rapidly after 65 the dataset would include only small samples of persons born in the years immediately following 1905; that may result in fairly large statistical fluctuations.

For the whole period from 1930 to 2000 the reduction of conceptions during Lent was found to be on average equal to: 14.1% ± 1%.

In contrast there was almost no reduction during Advent, the 40-day "Nativity Fast" that precedes Christmas.

4.3. Comparative perspective across countries

From the above discussion one would expect a smaller reduction effect in Catholic or Protestant countries than in Orthodox countries How can we test this conjecture?

As daily or weekly birth data are not be available for the early time periods that we wish to consider, we made the following simplified argument which will allow us to use monthly data.

(1) Firstly, our comparison will concern the time-interval 1931–1935 because this allows us to use the international monthly data given in [14].

(2) Secondly, we observe that in western countries Easter is on average on 8 April. This statement means that if we identify Easter with its daily location from 1 January on, then the average of these numbers over 30 (non-leap) years will be 98 days which corresponds to 8 April. Note that this is for Catholic and Protestant countries. For Orthodox Easter the average date is somewhat later, namely on 21 April. As in western countries Lent lasts 40 days, on average western Lent will last from 1 March to 8 April which means that if we identify Lent with March we will miss only $8/40 = 20\%$.

For Orthodox Easter the situation is less favorable. As Lent lasts 49 days it will be from 1 March to 21 April and will therefore be divided more equally (4/7 against 3/7) between March and April. By identifying Lent with March we will miss $21/49 = 43\%$.

There is an additional factor which makes the approximation more acceptable. If the religious injunction is followed fairly closely one would expect a rebound of conceptions after Easter. Such a rebound can indeed be observed; for instance in Bulgaria conceptions surged from 672 in March to 983 (+46%) in April. In western countries a surge can also be observed but which is much smaller. For instance in France from March to April conceptions rise from 939 to 1042 (+11%).

In other words, in Orthodox countries any reduction between 1 and 21 April may be offset by a surge in conceptions in the rest of the month. Thus, even in Orthodox countries, March appears to be a better month to consider than April.

Under the previous assumptions the conception reduction due to Lent can be represented by the ratio[8]:

R defined as: (conceptions in March)/(average of the conceptions in February and April)

By adding 9 months the conception ratio is then translated into a birth ratio (see Table 4).

4.4. Comparative perspective across time

One would expect a decrease of the Lent effect in the course of time. The data given in [13] allow us to follow the reduction from about 1930 to 2000. Needless to say, one would not be surprised to see a fairly sharp fall of the impact of religion during the 40 years of Communist regime. However, in order to assess the rapidity of the fall we should compare Romania with a non-Communist country. If we use again the approximation of Lent by the month of March, we can use French monthly birth data which cover a broad time interval ranging from 1650 to 2000. The comparison presented in Fig. 9 shows that in Romania the fall was about 6 times faster than in France.

8 Because of the "surge effect" the conceptions of April will be higher than they would be without such an effect. As a result, *R* will be lower than it should be.

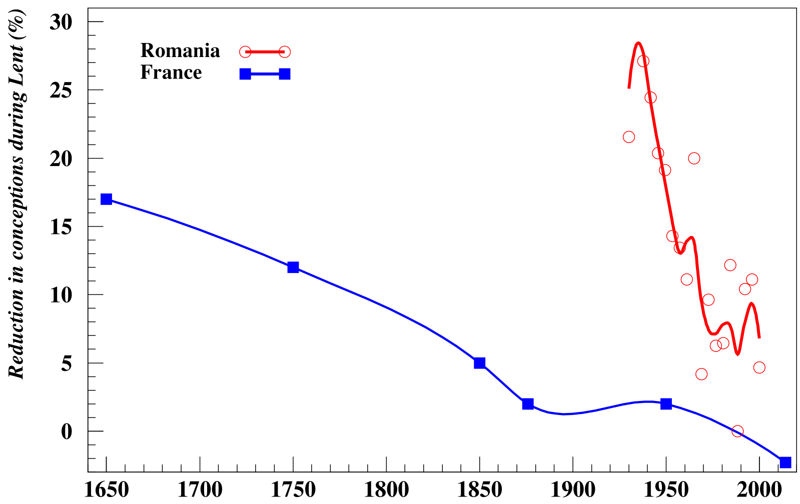

Fig. 9. Reduction of conceptions during Lent in France and Romania. The results for France are based on monthly birth data whereas those for Romania are based on daily data which is why they have a larger dispersion. Actually, prior to the 19th century, the records give the dates of baptisms. In order to accept them as proxies of birth dates one must assume that baptism followed birth fairly closely. Overall the fall of the Romanian curve is 6 times steeper than the fall of the French curve.
Source: Herteliu et al. [13], Houdaille [1,2], Régnier-Loilier [15], Dupâquier [16]

5. Conclusion

In this paper we have given interpretations of several kinds of birth rate troughs.

• For daily rates the main factor is the difference between working days and days off.

• For monthly rates any mass mortality event brings about a birth rate trough 9 months later because surviving people (and especially young people who can have children) suffer adverse living conditions. This effect was seen to be much stronger for influenza than for heat waves.

• The influence on birth rates of the religious environment can be seen statistically during special events such as the Fire Horse year or the Lent period.

The hallmark of the rules that we have studied is that, to varying degrees, they are valid in all countries for which we were able to find reliable data. Although in present-day France the influence of religious beliefs is small the analysis of historical data permitted to measure their strength in former centuries. In short, this analysis provides an objective way to assess the beliefs of people and how they change in the course of time.

In Fig. 7b we have seen that when two effects are in competition the resulting birth pattern becomes fairly intricate. Note that in this figure the death peaks remained unchanged; any change in the death pattern in the course of time would make the interpretation even more difficult. Similarly, in the language parallel proposed in the introduction, if the script or the meaning of a hieroglyph changes in the course of time this will affect the meaning of all sentences in which it occurs.

We plan to extend this investigation further when new data become available. For instance, using monthly birth data for China it would be interesting to test if there are conception surges in the "Golden week" (1–7 October) or during the "Spring festival", that is to say the week centered on the Chinese New Year. It can also be observed that so far we have no interpretation of birth rate peaks.

Because the question of birth seasonality has been studied for almost two centuries it gives an excellent opportunity to examine how the methodology has changed in the course of time. The discussion given in Appendix suggests that by renouncing the problem-oriented approach based on comparative analysis, present-day researchers put themselves in an unpromising condition.

Appendix. A historical view of former studies

It would be an impossible and useless task to try to summarize the immense literature on this topic. However, as our study brought us in contact with both historical and present-day papers it may be of interest to characterize the prevailing trend during the previous two centuries.

Monthly birth data series became available in European countries in the early 19th century and in the United States about one century later (due to the fact that it took some time to set up registration procedures in all states). Explaining the monthly distribution of births is a question which attracted the attention of researchers very early.

A.1. A pioneer study published in 1831

One of the first studies was published in 1831 by Louis René Villermé (1782–1863), a French physician and a pioneer of social epidemiology. In several respects his article is typical of those published at that time and it is interesting to note how it differs from present-day publications.

(1) It is a long article of one hundred pages.

(2) It is a *comparative study* which uses data not only for France but as well from many other countries: Great Britain, Germany (or rather Bavaria, Prussia, Wurtemberg for at that time Germany was not unified), Italy, the Netherlands, Russia, Sweden. It also uses data from various time periods going back for some places (e.g. Paris) to the 17th century. This kind of comparative methodology remained in use during the entire 19th century. Durkheim's renowned study of suicide (1897) used exactly the same methodology which, needless to say, was borrowed from physics where experimenters also perform as many observations as possible of any new phenomenon.

(3) Interestingly, 30 pages of the paper are statistical tables which contain all the data used by the author. Several of these datasets are still useful, as for instance the monthly birth numbers for Belgium and the Netherlands from 1815 to 1826. The thanks expressed in the notes to the tables reveal that the author had personal contacts with several foreign scholars from whom he received many of his data.

(4) In line with other scholars of the 19th century (e.g. [17]) Villermé does not hesitate to include in his study observations about animal species. This is of course in accordance with the perspective of comparative analysis. He observes for instance that for foxes, hares and wolves conception takes place between December and February which is fairly different from humans for whom the conception peak is in spring. Although nowadays animal "models" are also investigated it is not common to refer to them in demographic studies.

(5) Basically the paper states most of the general rules we currently know about. In other words, progress seems to have been fairly limited.

In summary, Villermé used a problem-oriented approach which leads him to collect such data that are the most appropriate for solving the questions under consideration.

A.2. Main characteristics of studies published in the past 50 years

The previous approach is in marked contrast with more recent studies. As illustrations we briefly discuss the following papers: (1) MacFarlane [18], (2) Seiver [19], (3) Lam and Miron [20,21], (4) McQuillan [22] (5) Huber and Fieder [23].

(1,2,3) and (4) are fairly broad papers whereas (5) focuses on a very specific point in a single country, namely Romania. In a problem-oriented research it is impossible to limit oneself to just one country for then it is impossible to know if the answer obtained in one case has any broad validity. Nonetheless. the one-case approach has become the norm nowadays.

Whereas (2) is also a single country investigation, (1,3) include data for several countries. However, they are not problem-oriented. As a matter of fact, they avoid raising any question. For instance, Lam and Miron [21] show that between the monthly birth patterns of Britain and the US state of Georgia there is a 6 month time lag. For two regions that are fairly similar in many respects this is rather unexpected; however the authors do not try to explain it. They do not even mention that this observation would warrant a further investigation.

At first sight, (4) seems the most promising paper for its title has a strong connection with our investigation. Unfortunately, it is a review paper which contains almost no data whatsoever. It is a collection of qualitative statements which provide little real understanding. How can one discuss fertility, basically a quantitative notion, without providing tables or graphs with data?

In summary, because they are not problem-oriented, the previous papers offer very little in terms of new understanding. They do not even give an "observational understanding" that is to say rules of broad validity which, thanks to their predictive power, allow further progress.

Naturally, we do not claim that the previous papers represent the whole literature on this topic, but at least they show a trend.

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