The physics of large-scale food crises

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Abstract
Investigating the “physics” of food crises consists in identifying features which are common to all large-scale food crises. One element which stands out is the fact that during a food crisis there is not only a surge in deaths but also a correlative temporary decline in conceptions and subsequent births. As a matter of fact, birth reduction may even start several months before the death surge and can therefore serve as an early warning signal of an impending crisis.

This scenario is studied in three cases of large-scale food crises. Finland (1868), India (1867–1907), China (1960–1961). It turns out that between the regional amplitudes of death spikes and birth troughs there is a power law relationship. This confirms what was already observed for the epidemic of 1918 in the United States (Richmond et al. 2018b).

In a second part of the paper we explain how this relationship can be used for the investigation of mass-mortality episodes in cases where direct death data are either uncertain or nonexistent.

Version of 8 July 2018

Key-words: Famine, death rate, birth rate, excess-death. Bertillon effect

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Introduction

A plea for comparative analysis

The title of the present paper was inspired by a book published seven years ago (Viswanathan et al. 2011) under the title: “The physics of foraging”. From foraging, i.e. the collection of food by animals, to food crises there is of course a smooth transition. However, in this title it is the mention of the word “physics” which was for us the most important source of inspiration for it means that the purpose of the book was to examine basic features of foraging that are shared by many species. To find common mechanisms in seemingly different phenomena has been a permanent objective of physics throughout its development over past centuries. Is there a common factor in the fall of apples, rain drops, meteorites and the “fall” of the Moon toward the Earth? We now know that the common factor is the gravitational attraction. Here, we will be guided by a similar agenda.

It can be observed that such a comparative approach was quite common in the late 19th century; see for instance the works of Louis-Alphonse Bertillon (1872), Alfred Espinas (1878), Jacques Bertillon (1892), Emile Durkheim (1895). One may deplore that in recent decades comparative studies of this kind (among which we do not include meta-analyses which is something different) have become rare.

The Bertillon effect: from heat-wave mortality to large-scale food crises

Here we will focus on the Bertillon effect (Bertillon 1892, Richmond et al. 2018a,b) which consists in the fact that any mass mortality is followed 9 months later by a birth rate trough. Our previous parallel with gravitation becomes particularly relevant here for indeed, just like gravity, the Bertillon effect has a broad range of applicability. There is a long chain of cases which goes from heat-waves, to epidemics, to earthquakes, to large-scale food crises. As in any chain, it is of particular interest to consider more closely its two extremities. Heat-waves in developed countries result in excess mortality of the order of 24% (Rey et al. 2007, p. 536, Table 1) whereas in the food crises that we are going to study mortality rates were increased by up to 140%. The successful identification of birth rate troughs in the wake of heat-waves required a skillful and

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1The paper was written by three physicists. However, we feel that our approach is very much in the spirit of the methodological guidelines defined by the French sociologist Emile Durkheim (1898). Incidentally, the same comparative approach was also used in our previously published papers in biodemography (http://www.lpthe.jussieu.fr/~roehner/biodemo.html).

2Note that the birth rate trough is much larger (usually about 10 times larger) than the reduction in births due to the fatalities. This was shown in detail in Richmond et al. (2018a) and can also be seen from the simple fact that excess fatalities would result in a one sided Heaviside fall not in a symmetrical and fairly narrow trough. This trough is mostly due to a temporary reduction in the conception rate among the survivors.

3In the sense of: [(observed deaths)-(deaths in normal years)]/(deaths in normal years).
pioneering analysis of daily birth data by Arnaud Régnier-Loilier (2010 a,b). The reason why heat waves display only a faint Bertillon effect is not only due to low excess mortality but also to it being concentrated in elderly people which makes it irrelevant for birth rates.

Why did we say that heat-wave cases constitute the beginning of the chain? One could of course consider diseases (e.g. the Lyme disease) which have even lower mortality. However, as the birth rate troughs of heat-waves are already at the limit of what can be observed, the Bertillon effect for Lyme disease would be inobservable. It would be like a pulsar which is known to exist but is too far away to be seen with an optical telescope.

In the cases considered in the present study the Bertillon effect is so massive that it can be identified (and studied even at regional level) with annual vital statistics.

From well documented cases to uncertain situations

Why did we choose to focus on the three cases selected? The main reason is that these cases are massive and statistically fairly well documented.

In contrast, there are many cases of mass mortality for which there is considerable uncertainty. Thanks to the death-birth relationship (to be stated below) one is in good position to throw new light on such episodes. How?

Most countries, even those which do not have a reliable statistical registration infrastructure, conduct censuses. Because this is done periodically (e.g. once in a decade) it does not require a permanent organization. As will be shown below, the distribution of the population by age measured in a census gives a fairly accurate picture of birth rate changes in the years preceding the census. For instance, the census of 1982 in China gives a good picture of the birth rate squeeze that occurred in several provinces in 1961. Then, through the relationship between birth troughs and death spikes one can get an estimate of the mortality. Even though not perfect, such estimates give at least a rough picture of what happened.

Outline

Our investigation will proceed through the following steps.

1. First, we present the three famine cases which will be studied. Apart from giving some social and historical background information, we will discuss the origin, reliability and accuracy of the birth and death data.

2. Then, in each case we describe the Bertillon death-birth connection.

3. In order to get a comparative view we bring together the three Bertillon relationships and we compare them with the results already obtained in Richmond et al.

4Even for persons in age of having children the birth rate trough is only marginally due to those who die. Most of the effect comes from the much larger number of persons who are affected but do not die.
We show how to retrieve past annual birth rates from a population pyramid.

Finally, in our conclusion, we develop two examples in which mortality rates are derived from census data.

**PART 1: QUANTIFICATION OF THE BERTillon EFFECT**

**Background information for the crises**

**Causes of death**

First of all, we should explain why we prefer to use the expression “food crises” rather than “famines”. The word “famine” elicits images of people starving to death. Although, this may of course exist as documented by impressive Internet pictures of children almost reduced to their bones, death by starvation represents only a small fraction of the global death toll of food crises. This can be illustrated by data from Finish and Indian sources.

- The data given in Finland 1 (p. XXXIV) and Finland 2 (p. 421-422) tell us that during the crisis of 1868 death by starvation represented only 1.71% of the deaths. The main cause of death was typhus (43%), followed by tuberculosis (5.84%), dysentery (5.70%) and smallpox (3.02%).
- Data for the food crisis of 1942–1944 in India are given in Maharatna (1992, p. 331). Death by starvation represented 2.1% of the deaths. The main cause of death was fever due to diseases (mainly malaria) which accounted for 34.8% followed by scabies (18.4%) and dysentery (10.9%).

In short, at symptoms level, food scarcity crises have a close resemblance with epidemics.

**Crisis of 1868 in Finland**

Immediate causes such as a rainy and cold summers in 1866 and 1867 can be mentioned but in order to get a real understanding the crisis of 1868 should not be seen as an isolated event. In fact, there had been similar crises in 1833 and 1856. albeit of smaller magnitude (Flora et al. 1987, p, 24,51). Whereas in the 1840s the average annual death rate was around 25 0/00 it reached 46 0/00 in 1833, 34 0/00 in 1856 and 78 0/00 in 1868.

The main factor in this succession of crises was certainly the rapid growth of the population. Between 1811 and 1865 it increased by 66% which is twice the 30%
increase in France in the same time interval (Flora et al. 1987, p. 55-56). This 66% increase represented an average annual increase of 1.20% (against 0.55% in France). Certainly agricultural production did not increase at the same rate which means that any bad harvest due to adverse weather conditions would result in malnutrition or a more serious crisis. The annual death rate of 78‰ reached in 1868 in Finland was one of the highest ever observed anywhere.

The severity of a food scarcity is best judged by the death rate peak for this is a fairly intrinsic metric. In contrast excess-deaths are very dependent on the level of the baseline death rate chosen to define normal conditions.

It is true that at the level of Indian provinces the death rate reached similar values: for instance in 1900 it reached 88 in the “Central Provinces”. However, if nationwide data were available they would certainly show lower peak values for in such a large land as India the crises were not completely synchronous.

**Food crises in India**

Between 1860 and 1910 there were recurrent food crises in India but most of them were limited to some parts of the country. A brief description can be found in Roehner (1995, p.5-6).

Can one explain the famines in India in the same way as the famines in Finland that is to say by a rapid increase of the population. The answer is no. Assuming that the population estimate given for 1820, namely 209 millions is indeed reliable, one finds for the period 1820–1865 an average annual increase rate of only 0.27%.

However, if the population stagnated the amount of food available in India may have decreased. One can mention three reasons for a shrinking food supply (Davis 2000, p. 59-66).

- Between 1875 and 1900 Indian annual grain exports to Great Britain increased from 3 to 10 million tons, equivalent to the annual nutrition of 25 million people. Davis does not give trade data for the period before 1875. However, it is known that as a result of the repeal of the corn tariff around 1850 Britain’s dependence on imported grain increased from 2% in the the 1830s, to 24% in the 1860s, and 65% (for wheat) in the 1880s. Thus, it is quite possible that the drain on Indian grain started before 1875.

- In Berar (central India) the acreage of cotton doubled between 1875 and 1900.

- Although a colony, with regard to its budget India was treated like an independent country. This meant reimbursing the stockholders of the “East India Company”, paying the costs of the 1857 revolt, supporting an army of about 100,000 that was employed not only in India but also in foreign war theaters (e.g. Afghanistan, Tibet, Egypt, Ethiopia, Sudan). Military expenditures alone represented about one third of
the budget. As a result, little funds were available for agricultural improvement.

Having said that, in India just as in Finland and in China, the immediate causes of the crises were unfavorable weather conditions, particularly drought which in Madras and Bombay provinces resulted from a reduced monsoon rain season.

**Food crisis in China, 1960–1961**

The explanation given for Finland also applies to China and in fact to even greater degree. From 1949 to 1959 the Chinese population increased from 541 to 672 millions, an increase of 24.2% which represented an average annual increase of 2.20%. This is 4 times faster than the French rate of 0.55% that we took as a yardstick in discussing the case of Finland. It is true that between 1953 and 1957 population and foodgrain production increased at the same rate of 2.0% annually: the population from 588 to 646 millions and the foodgrain production from 168 to 185 million tons. However, after a bumper crop of 212 million tons in 1958 it declined due to bad weather conditions to the point of being reduced in 1960 to its level of 1957 at which time there had been about 50 million fewer Chinese to feed (SNIE 1961, p.3).

At the same time the death rate fell from 20 %/00 to about 10 %/00. It is the fall in the death rate which brought about the rapid population increase for the birth rate remained stable at around 40 %/00. Fig. 1 shows that even at its peak value in 1960 the death rate reaches only 25 %/00 (Ren kou 1988, p. 268) which is lower than the death rate in Bengal under normal conditions and only slightly higher than the death rate in 1949. In short, instead of people starving to death, one should rather think of the situation as similar to the one of 1949. It is true that the situation may have been more tragic in some specific provinces as for instance Anhui or Sichuan. However, this was not really new for, as we will see below, the best predictor for regional death rates in 1960 was the situation one decade earlier.

**Comparative graph**

Fig. 1 shows the changes in death rates in India and China. For the sake of clarity we did not represent the curve for Finland on the same graph; however, it can be noted that the baseline death rate before the Great Famine of 1868 was around 28 %/00 and that the death rate peak reached 78 %/00. In a general way, for a given peak value, the lower the baseline rate, the higher the excess mortality with respect to this baseline. The fact that for China the baseline level was 2 or 3 times lower than in India is the main reason for a substantially higher excess death number.

In Fig. 1 it may appear surprising that in 1931–1940 the death rate in Bengal was about 1.5 times higher than the rate for 1874–875 in Madras. The most likely ex-

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6 According to the SNIE (1961, p.1) report discussed in Appendix A: “Widespread famine does not appear to be at hand but in some provinces people are now on a bare subsistence diet.”
Fig. 1 Comparison of famines in India and China. The vertical scale is the same for the 3 curves. As there are no nationwide data for India the curve corresponds to data for the province of Madras in the south east of India. Sources: Maharatna (1992, p.55), Ren kou (1988, p.278).

planation is under-reporting. The registration of deaths started around 1870 and, as is often observed, the scope and completeness of the registration increased progressively in the course of following decades. In the 1940s, the corrective factors used by various authors still ranged from 1.32 to 1.70 (Maharatma p. 228). This suggests that in the 1870s under-reporting may have been more serious, may be by a factor 2.

The Bertillon death-birth relationship

In each of the previous cases death and birth data are available not only at national level but also at provincial level. This will allow us to carry out a regression analysis in the same spirit as in Richmond et al. (2018b). Here, however we will have to work with yearly (not monthly) data. It is to maintain accuracy that we limited ourselves to massive events. As in many countries only annual data are available, it is important to
see whether or not in such cases the Bertillon effect can be analyzed in a meaningful way.

**Bertillon effect in Finland: food crisis of 1868**

Fig. 2 shows the Bertillon effect for the 8 provinces which composed Finland in the 1860s.

![Amplitude of death peaks (1868) vs. Amplitude of birth troughs (1868)](image)

**Fig. 2 Finland, 1868: relationship between the amplitudes of death spikes and birth troughs.** As the graph is a log-log plot it means that: \( A_b = CA_d^\alpha \), where \( \alpha = 0.50 \pm 0.26 \) and \( C = 0.89 \pm 0.06 \) (the error bars are for a confidence level of 0.95); the coefficient of linear correlation is 0.83. Each number corresponds to one of the 8 governments (i.e. provinces) which composed Finland. Their names are as follows: 1=Uudenmaan (S), 2=Turun ja Porin (SW), 3=Hämeenlinnan (S), 4=Wiipurin (SE), 5=Mikkelin (SE), 6=Kuopion (E), 7=Waasan (SW), 8=Oulun (N). *Sources: Finland (1871, p.34,XII), Finland (1902, p.274,397)*

As monthly data are available for the whole country, we know that the death rate peak occurred in May 1868; therefore, as expected, the center of the birth trough will be in December 1868–January 1869. In other words the birth trough will be split in two parts, one part in late 1868 and the other in early 1869. However, because of the rebound effect \(^7\) the annual birth number for 1869 is higher than the one for 1868. That is why in Fig. 2 the vertical scale displays births of 1868 and not 1869.

**Birth troughs seen as a sensitive detector of population suffering**

At first sight it might seem that the absence of a death spike, i.e. \( A_d = 1 \) means that

\(^7\)The rebound effect occurs in the months immediately following the trough; it is a compensating rise of the birth rate above normal baseline level (see Maharatna 1992, p. 380 and Richmond et al. 2018a). In other words it is a return to equilibrium marked by an “overshooting” episode.
the situation is normal and should therefore be associated with $A_b = 1$. However, the fact that there are no excess-deaths does not mean that the population does not suffer. A simple illustration is a non fatal disease which nevertheless makes people ill. The 2003 SARS epidemic in Hong Kong discussed in Richmond et al. (2018a) was a situation of this kind. Although not strictly equal to zero, the death toll was only 40 per million. Nevertheless, the threat and disorganization due to the epidemic produced an excess birth trough of 6% ($A_b = 1.06$).

In the same line of thought it will be seen in subsequent cases that usually the birth rate starts to fall in an early stage at a moment when no increase of the death rate can be detected. In other words, birth troughs are a detector of population suffering that is more sensitive than $A_d$.

**Bertillon effect in India: time series of food crisis**

Here “India” refers to the British colony before its division into Bangladesh, India and Pakistan.

As already observed there are no nation-wide data for India in spite of the fact that some food crises extended to several parts of the country. Instead one has data separately for several provinces: Bombay, Central Provinces, Madras, Punjab, United Provinces. Fig.3a,b displays the basic mechanism of food crises: as the death toll increases the birth rate decreases. One may wonder why here, in contrast to Finland, the birth trough occurs in the year following the death spike. Monthly data that are available in some cases (Dyson 1991a,b, 1993 and Maharatna 1992, p. 235) show that usually the maximum of the deaths occurred in August at the beginning of the wet season. The reason for that comes from the fact that the main cause of mortality is malaria whose spread is favored by humidity.

With deaths spiking in August instead of May as was the case in Finland the effects of reduced conception will be mostly visible in the following year.

Fig. 3a and 3b show that the analysis performed in Richmond et al. (2018a) on monthly data can be repeated in a similar way with annual data.

**Bertillon effect in India: global death-birth relationship**

Next, we wish to discover the relationship existing between the amplitudes of death spikes and birth troughs of different crises. This is summarized in Fig. 4. There is again a power-law relationship.

**Bertillon effect in China: time series of the food crisis of 1960-1961**

Of the three countries considered in this paper it is for the case of China that we have the most complete data set. Annual data are given for over 20 provinces from 1955 to 1985. In what follows we will focus on a 10-year interval centered on the crisis of 1960-1961.
Fig. 3a, b Bombay (1895-1903). There are two food crises in the time interval 1895-1903: first one of small magnitude in 1896-1897 and then the more serious crisis of 1899-1900. The right-hand graph (where the birth curve was shifted and inverted) makes manifest that both death spikes gave rise to a birth trough in the following year. Source: Maharatna (1992, p.55).

Fig. 4 India (1877-1908). Relationship between the amplitudes of death spikes and birth troughs. The relationship is as follows: $A_b = CA_d^\alpha$, where $\alpha = 0.30 \pm 0.16$ and $C = 1.01 \pm 0.06$. The coefficient of linear correlation is: 0.81. The correspondence between the numbers and the provinces is as follows: 1=Madras (1877), 2=Bombay (1877), 3=Bombay (1900), 4=Punjab (1900), 5=Central Provinces (1897), 6=United Provinces (1908), 7=Bombay (1897), 8=Central Provinces (1897), 9=Berar (1897). Source: Maharatna (1992, p.55).
Fig. 4 shows typical graphs for 4 different provinces. In a general way, the crisis was more serious in South China than in North China and in the south the severity increased from east to west. Apart from Beijing, the three other selected provinces are all located at the same latitude (about 500 km south of Shanghai): Fujian is on the Pacific coast, Hunan in central China and Sichuan about 700km to the west of Hunan. The graphs show very clearly two characteristics of the Bertillon effect.

Fig. 5 Birth and death rates in 4 Chinese provinces. The curve of deaths is in black with filled squares; the curve of birth is in red with filled circles. The graphs are ranked by order of increasing severity. It can be seen that the fall of the birth rates in 1957, 1958 provide so to say early warnings of an impeding crisis. The fact that the minima of the birth troughs occur in 1861 shows that the mortality rates certainly peaked in the second half of 1960. Source: Ren kou (1988)
- The one year time lag between death peaks and birth troughs
- The birth rate rebounds in the two or three years following the troughs.

In the next subsection, in order to find out the relationship between the amplitudes of death peaks and birth troughs, we extend this analysis to 22 provinces

**Bertillon effect in China: global death-birth relationship**

Fig. 6 shows the relationship between death peaks and birth troughs. As in Finland and India it can be described by a power law. The exponent is about the same as in Finland.

![Fig. 6](chart)

Fig. 6 China 1959-1961. Relationship between the amplitudes of death spikes and birth troughs. The relationship between the amplitudes of the death and birth rates is as follows: \( A_b = CA_d^\alpha \), where \( \alpha = 0.42 \pm 0.16 \) and \( C = 1.38 \pm 0.06 \). The coefficient of linear correlation is: 0.76. The labels are the first three letters of the names of the provinces except for the following whose first three letters would have been identical: SHA=Shanxi, SHN=Shanghai, SHG=Shandong, GUA=Guangdong, GUI=Guanxi, GUZ=Guizhou. *Source: Ren kou (1988)*

**Structural fragility**

One may wonder what made the crisis more serious in some provinces than in others. We have already mentioned that globally the north was less affected than the south and the east less than the west. However, besides these fairly loose observations there
is another which is both simpler and more revealing. It consists in the fact that the provinces which have the highest death rate peaks in 1960 are those which already had the highest death rate in the normal years before the crisis. This is illustrated graphically in Fig. 7.

![Figure 7: Relationship between the death rates in 1956 and in 1960 (food crisis).](image)

**Fig. 7** Relationship between the death rates in 1956 and in 1960 (food crisis). The coefficient of linear correlation is: 0.81. The labels are the same as in Fig.5. *Source: Ren kou (1988)*

Is there a similar connection between normal and peak death rates in Finland and in India? It is impossible to say because in those cases the number of separate provinces for which data are available is too small.

What interpretation can one give of the effect shown in Fig. 6? The higher death rates in normal times suggest structural fragility factors. To get better insight it is useful to compare extreme cases. On one end we consider the northern provinces of Heilongjiang and Jilin where the crisis was subdued while on the other end we consider Anhui and Sichuan where it was very severe.

In Table 1 we computed the population growth between 1954 and 1959. A much faster growth in Anhui-Sichuan would suggest that, as was indeed the case for the whole country, the increase of food supply could not match the population growth. However, the data in Table 1 do not show a faster population increase in Anhui-
Sichuan. As a matter of fact, had it existed such a faster growth would not explain that the death rate in Anhui-Sichuan was already higher in 1956. This fact rather suggests that there was a structural fragility that was already present in 1956 but had an aggravated effect in 1960.

### Table 1: Regional fragility

|        | Population (10^6) | Population increase | Population density (per sq-km) | Death rate 1954 (per 1,000) | Death rate 1960 (per 1,000) |
|--------|------------------|---------------------|-------------------------------|--------------------------|--------------------------|
| Jilin  | 11.7             | 13.2                | 13%                           | 60                       | 10.3                     | 10.1                     |
| Heilongjiang | 12.7        | 16.9                | 33%                           | 37                       | 10.5                     | 10.5                     |
| Anhui  | 31.7             | 34.4                | 8.5%                          | 224                      | 16.4                     | 50.2                     |
| Sichuan| 64.4             | 73.7                | 14%                           | 134                      | 15.4                     | 47.8                     |

Notes: Jilin and Heilongjiang were little affected by the crisis whereas Anhui and Sichuan were the two provinces where the crisis was the most severe. It seems that population density is the main factor which can explain this difference; in Anhui-Sichuan it was on average 3.7 times larger than in Jilin-Heilongjiang. This created a permanent fragility and sensitivity to weather conditions which is revealed by the high death rates even before the crisis.
Source: Ren kou (1988)

The data in Table 1 show that the population density was far higher in Anhui-Sichuan than in Jilin-Heilongjiang. The difference is all the more striking because in contrast to Jilin-Heilongjiang Sichuan had at that time almost no industry.

Another contributing factor was the regional prevalence differential of infectious diseases. It is well known that malnutrition reduces the ability of the organism to fight infection. For tuberculosis in 1990 the prevalence was 147 per 100,000 in the East, 198 in the Center and 216 in the west (China Tuberculosis Control Collaboration 2004, p.421)

We will not develop this analysis further for it would lead us too far away from the main purpose of our paper which to focus on general rules. In the next subsection we compare the regression lines in Finland, India and China.

**Comparison of the regression parameters**

When the three regression lines are drawn on the same graph one can compare their slopes (given by the exponent \( \alpha \)) and their levels (given by the coefficient \( C \)). The level is given by the birth trough amplitude for a given death peak amplitude. One should realize that this depend very much upon how the birth deficit is divided between the two years. Thus, for a death peak in May (as in Finland) the birth deficit will be divided almost equally between 1868 and 1869. On the contrary, if deaths
had peaked in November 1868 then the whole birth deficit would occur in 1869. In other words, to make this comparison significant one would need monthly data.

With respect to the slopes we observe that they are fairly similar for Finland and China but 50% smaller for India. Regarding the value of $\alpha$ in India one can observe that in this country the data cover several food crises in successive years whereas in Finland and China they cover a single crisis. However, it is not clear why this should lead to a lower $\alpha$.

For the influenza epidemic of October 1918 in the United States the slope was (Richmond et al. 2018b): $\alpha = 0.19 \pm 0.1$ and $C = 1.28 \pm 0.22$. Here, a lower value of $\alpha$ makes sense. To make the argument simpler, let us consider as an approximation that $C = 1$; this means that in all cases the regression line starts from the point $(1, 1)$. Then the question becomes: “For a given death peak how many people will suffer to the point of reducing conceptions?” It makes sense to observe that during a food crisis more people do suffer, and suffer more severely, than during an influenza epidemic. An obvious reason is that the influenza epidemic was much shorter than any of the food-crises that we considered. It lasted only about one month, from 15 October to 15 November 1918 whereas the food crises lasted more than one year.

In the last section before the conclusion we will show how the death-birth relationship can be used as an exploration tool for historical mass mortality events.

**PART 2: MASS MORTALITY EPISODES EXPLORED THROUGH THE BERTILLON EFFECT**

**Why are mortality statistics often uncertain?**

The production of vital statistics comprises two fairly different tasks.

- In order to register individual births and deaths one needs a network extending to hospitals and doctors of the whole country. This is a challenging task as can be seen from the fact that in a vast country like the United States it took several decades to extend the registration network to all states. The task was completed only around 1930. Even once established, registration networks may be overwhelmed during mass mortality episodes.

- The second task is the organization of censuses. Although by no means an easy task, the organization of censuses does not require a permanent network extending to the whole country. In a time span of 3 or 4 months the same team of census officers can move from region to region until the whole country has been covered.

The fact that the organization of a census is a much less demanding task than daily registration is demonstrated by the observation that the first US census took place
about one century before the national registration network was completed.

**How can one derive annual birth numbers from census records?**

In principle, a census does not give any information about births or deaths but it gives the age of all people and from these data one can derive approximate birth data. This is illustrated in Fig. 8a,b.

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**Fig. 8a,b  Derivation of birth data from a population pyramid.** (a) The huge indentation is due to the birth deficit in 1960-1961. The population pyramid of Anhui province was built with the data of the census of 1982. Each step represents an age group born in a single year. Males are on the left and females on the right. The birth rate trough corresponds to people who were 1982 − 1961 = 21 year old at the moment of the census. People older than 21 were born before 1961 and people younger than 21 were born after 1961. In this way one can reconstitute approximate birth data for the whole period from 1955 to 1982. (b) Graph 7b is for males; its horizontal axis shows the years of birth as derived from the ages recorded in the census of 1982. It shows a fairly good agreement between the real birth data and the approximate birth data derived from the population pyramid. *Sources: Population pyramid: IPUMS. Birth data: Ren kou (1988).*

In what sense are the data derived from the population pyramid approximate birth numbers? In principle the size $b'(1982)$ of the age group $0−1$ of the population pyramid should be equal to the number $b(1982)$ of births in 1982. The fact that in graph 7b the two points are not identical is because we have been using a 1% sample of the census of 1982. This gives an idea of the statistical fluctuations. More generally, the individuals aged $x$ in 1982 were born in $y_b = 1982 − x$.

For instance, the individuals born in $y_b = 1970$ will be 12 year old in 1982. Naturally, during these 12 years some of these children died or moved from Anhui to another place (whether in China or abroad); conversely some children may have moved into Anhui. If these population movements are important the size of the 12-year age group will have little to do with the number of births in 1970. On the contrary, if
there were few population movements a comparison of the numbers $b'(x)$ and $b(x)$ will tell us how well the registration system was working. Generally speaking, the registration of births is more reliable than the registration of deaths for at least two reasons.

- When funeral services are overwhelmed by the number of deceased people it may happen that they are buried by relatives or neighbors without being registered, especially in times of epidemics. On the contrary, as there are no birth rate spikes the birth registration services will not get overwhelmed. In addition the registration of newborns does not need to be done immediately after birth, it can be done at any time.

- Politically, dead people are usually a more sensitive matter than newborns. The authorities may wish to publish under-estimated death numbers.

**Preliminary test of the methodology on influenza deaths in Pennsylvania**

First of all, before using it as an exploration tool, we wish to test the accuracy of the methodology on a case in which the death toll is known. Why did we select for our test the influenza epidemic in Pennsylvania? The impact of the disease was particularly severe in Pennsylvania. The amplitude of the death peak of 1918 (with respect to the average of the 1917 and 1919 numbers) was 1.56 in Pennsylvania but only 1.35 for the whole country (or more precisely for all death registration states).

The challenge now is to see if we can derive the death peak amplitude solely from the age-group data given by the census of 1930. For that purpose we need to go through the following steps.

1. First, as was already done in the previous subsection, we derive from the age-groups given by the census of 1930 proxy birth numbers. To distinguish these proxy birth numbers from the real birth numbers (given by the registration network) they will be called *census birth numbers*. This step is done in Fig. 9a,b. In contrast with Fig. 8a,b here there is no huge trough. Before doing the test we could not know whether or not the small trough of 1918 would be covered by the background noise. Fortunately, it turns out that it can be identified. Its amplitude is 1.09.

2. The second step is to use the death-birth relationship to derive the amplitude of the death peak. As the level of the regression line is not well defined (as was explained earlier it depends upon the month of the death spike) we take again $C = 1$ for the multiplicative constant. Thus, using the value of $\alpha$ given previously, one gets:

$$A_b = A_{d}^{0.19} \Rightarrow A_d = A_{b}^{1/0.19} = 1.09^{5.26} = 1.57$$

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\[8\text{For instance, according to "Résumé rétrospectif (1907, p. 368), the death rate in Ireland in the period 1864–1870 was 16.6\% which was the lowest rate among all European countries. It was lower than in England and Wales (22.5), Sweden (20.2), Denmark (19.9) or Prussia (27.0). Most likely such a small rate resulted from under-reporting.\}
(3) Now, in order to derive the death rate in 1918 from the amplitude of the death peak, we need an estimate for the death rate in normal times. Although in some cases this death rate may be known, most often it is not. In the two cases considered below the normal death rates are not known for the simple reason that there was no registration network. In such a case one takes the death rate in a region that is similar in terms of socio-economic conditions. For instance one may take the death rate in 1915 in Sweden which is 14.7 ‰ (Flora et al. 1987, p.73). Here, as the death rate in Pennsylvania is in fact well known (for in 1915 it was already a death registration state) we can check whether the Swedish proxy is reasonable. It is indeed for in Pennsylvania in 1915 the death rate was 13.2 ‰. Thus, the predicted death rate in 1918 becomes: \( \mu = 1.57 \times 14.7 = 23.1 \). Compared with the real value of 18.1 ‰ there is a difference of 28%. This could seem high, but one should remember that in such matters the estimates by various authors often differ by 100% or more. In the first case considered below, no estimate whatsoever was available and in the second case the official estimate may have been highly exaggerated.

**Georgia during the American Civil War**
As an illustration of the kind of situation for which the birth-death method may be useful consider the state of Georgia in 1864, the year of the Civil War during which General Sherman led Union troops through Georgia on what is called the “March to the Sea” (Nov.–Dec 1864) which resulted in great damages.

![Figure 10: Reduction in birth rates during the Civil War in Georgia and Virginia](image)

The horizontal axis shows the year of birth as derived from the age at the census of 1870. The fact that in 1861 and 1870 the levels are nearly the same shows that there was no permanent emigration or immigration between the year of birth and the census year. Source: 1% sample of the census of 1870 from the database of IPUMS, USA.

At that time Georgia was not a registration state which means that no death data were recorded. As a result, one has no idea of the civilian death toll of the “March to the Sea”. However, there was a census in 1870 through which one can measure the birth numbers in earlier years. The population pyramid shows that there was a birth trough of amplitude 1.33 and of width 3 years (Fig. 10). Applying the relationship between birth troughs and death peaks leads to a death peak amplitude $A_d = (1/C)A_b^{1/\alpha}$. For the sake of simplicity we take $C = 1$, $\alpha = 0.5$ which will give a fairly conservative death estimate: $A_d = 1.33^2 = 1.77$. For the average death rate in 1861–1870 time we take the rate of Sweden namely 20 ‰ (Résumé rétrospectif 1907, p. 368). Thus the peak rate in 1864 was: $1.77 \times 20 = 35 \%_{00}$. In 1860 the population of Georgia was about 1 million; this leads to an excess-death toll of $15 \times 1000 = 15,000$. There may be a additional excess-deaths in 1861–1863 but as we do not know the width of the death peak (usually it is more narrow than the birth trough) we will not try to estimate them.
The figure of 15,000 excess-deaths should be seen as a tentative estimate because it is not obvious that the death-birth relationship derived from food crises can also be used for a war time situation. During wars, the fact that husbands and wives are separated may inflate the birth troughs to an extent which may critically depend upon how frequently servicemen can return home. If the birth troughs of Fig. 8 are inflated through the separation effect, the figure of 15,000 will be an over-estimate.

**Measles epidemic in Fiji Islands in 1875**

It is claimed that the measles epidemic of 1875 in Fiji claimed one third of the population which was assumed to have been 150,000 before the epidemic (McArthur 1967, p.8). Note that both the population and the death toll are merely estimates made by western visitors.\(^9\)

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\(^9\)For instance, the population estimates published by different visitors range from 100,000 to 300,000.

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**Fig. 11** **Was there a devastating measles epidemic in Fiji in 1875?** The ages given on the left-hand side correspond to the age-groups in 1921. One expects a birth trough in 1875. In the census of 1921 this trough will be seen as a reduced size of the age-group that is 49 year old resulting in a reduced 49 year old age-group. Based on a death-birth relationship with an exponent \(\alpha = 0.5\), one would expect a reduction of the corresponding 5-year age group as indicated in green. **Source:** Fiji census of 1921, the first in which ages were recorded, cited in McArthur (1967, p.38).

This sounds somewhat surprising when compared to the death toll of the influenza epidemic of 1918 which was only 5%. This last figure is probably more reliable than the one for 1875 because in the meanwhile the procedure for births and deaths registration was improved by the British administration. Fig. 11 is based on the census of 1921. This was not the first one but in the censuses of 1879, 1881, 1891, 1901 and 1911 only 4 age groups were distinguished, namely: children, youths, adults and aged.
Even without doing any further calculation a comparison with Anhui (where the death toll was 5%) shows that the 33% claim seems dubious. It is true that instead of annual data here we have only 5-year averages but in Anhui the contraction would still be clearly visible on 5-year averages. More specifically, a calculation involves the following steps. (i) Computation of the amplitude of the death spike based on the 33% death toll. (ii) Computation of the amplitude of the birth trough based on the death-birth relationship; for $\alpha$ we selected $\alpha = 0.5$ but taking another value (e.g. $\alpha = 0.3$) would not make a great difference. (iii) Finally, from the amplitude of the birth trough one derives the expected contraction of the 5-year age group (shown in green in Fig. 11).

One may wonder why British authorities were favorable to the thesis of a big drop in the Fijian population\textsuperscript{10}. One reason which comes to mind is that in 1879 started a massive transfer of Indian indentured workers to Fiji which had the purpose of providing the manpower needed on sugar cane plantations. By 1946 the Indian community had developed to the point of being larger than the native Fijian population.

**Conclusion**

**Outline of the exploration of food crises**

In his seminal paper Jacques Bertillon used weekly and monthly birth and death data (Bertillon 1892). We wished to see to what extent his analysis can also be performed using annual data for in many countries only annual vital statistics are publicly available. It was shown that the death-birth effect can be analyzed in a significant way provided one considers events marked by large-scale mortality. The annual death birth data were found to be compatible with the 9-month time lag revealed by weekly and monthly data (see Fig. 3.5).

By observing regional death peaks and birth troughs we found a power law relationship between their respective amplitudes in confirmation of a similar connection already observed in Richmond et al. (2018b).

**Agenda for future explorations of mass mortality episodes**

The spirit of a death registration network is to go bottom up. Starting from block level one should move up to county, state and nation level. At each step the death numbers should be aggregated until one gets to a total number for the whole country. Any death estimate made at the macro-level without being supported by appropriate

\textsuperscript{10}In British accounts the gravity of this epidemic is heavily emphasized (see McArthur 1967, p.8). The following excerpt is from a report by a commission in 1893. In 1875 “the people were estimated to number about 150,000, and it is recorded, probably with fair exactitude, that 40,000 died from measles during the epidemic which overran the whole archipelago in the space of 4 months. Whether the Fijians who survived have had their stamina permanently lowered can only be a matter for conjecture.”
data at micro-level should be considered as suspicious. Unfortunately in many cases of interest the data that would permit a bottom up procedure are simply not available. The methodology developed in the previous section allows us to use censuses made decades after the mass mortality. For instance, in the case of the Fiji Islands we have been using a census made 4 decades after the epidemic of 1875. We believe that this procedure can bring new light in many dubious estimates.

Appendix A: Specific features of the crisis in China

It seems that in the course of the past two decades the factual description of the food crisis of 1960-1961 has progressively been replaced by accounts based on ill-founded stories. The Wikipedia articles entitled: “Great China famine” and “History of agriculture in the People’s Republic of China” illustrate this tendency. The second one contents claims not based on any reference or outright mistake. Science is not only about building nice models, first and foremost it means starting from the right facts. In order to come back to a more scientific description, it is important to collect as many hard data as possible. By hard data we mean data that can be checked in some way. This is for instance the case of grain trade data because such figures are published by the two trade partners, first as exports, then as imports. It is the purpose of the present appendix to present a number of useful data.

Parallel with the food crisis and meteorological situation of 1878

An article entitled “La famine en Chine” [Famine in China] was published in 1880 in a French scientific journal (Margollé 1880) which describes a meteorological situation very similar to the one in 1959–1960, namely a severe drought in north China over 3 years together with floodings in south China. In this article, the two phenomena are explained by the existence of a strong high altitude air circulation from west to east which prevented the steady humid flow originating in the south from reaching the north. Instead the accumulated humidity would eventually be released in central and south China and provoke the floodings.

The severity of the famine was described as follows. “Between 1876 and 1878, a lethal drought-famine struck the five northern provinces of Shanxi, Henan, Shandong, Hebei, and Shaanxi. By the time the rains returned late in 1878, an estimated 9 to 13 million of the affected area’s total population of about 108 million people had perished (Legge 1878, Edgerton-Tarpley 2008). The publication of 1878 by the “Committee of the China Famine Relief Fund” shows that this famine triggered a mobilization in western countries. Relief operations opened a road to the action of western missionaries. The famine took place 14 years after western powers helped

11Such as the claim that China did not import grains before 1962 which, as will be seen below, is not correct.
the imperial government to defeat the Taiping rebellion.

**Excess deaths**

When the death rate of 1958 is taken as the baseline the peak of 1958–1961 gives an excess death toll of 14 millions, an impressive figure. As in Finland the crisis was a two step process: the fast population growth made the country vulnerable to adverse weather conditions; then in to successive years 1959 and 1960 the country was hit by severe droughts. We will also try to assess the role of the “Great Leap” policy.

**Wheat imports**

The situation was aggravated by the difficulties and delays in importing grains. The USSR was unable to export grains to China. A table of the SNIE (1961) reports that there were no Soviet grain exports to China. Soviet-China relations already started to sour in 1960. In July-August 1960 the USSR abruptly withdrew nearly all of the 2,500 Soviet industrial technicians present in China; moreover, a disruption in oil delivery created a shortage of petroleum products in late 1960 (SNIE 1961, p. 4).

After 1950 the United States had put in place a drastic trade embargo which, through the CHICOM committee, involved also US allies. In 1959 the US had a large surplus of wheat. An article of 8 November 1959 in the New York Times is entitled “Wheat surplus is a big headache”. It says that at the start of the crop year the surplus stood at 1.27 billion bushels (on the basis of one bushel of wheat weighing 30kg

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12 If one takes as baseline the level of 1950 the excess death toll is about 7 millions which is of the order of magnitude of the recurrent famines that occurred in the 1920s and 1930s.

13 The following articles published in the “New York Times” provide some useful glimpses into the situation.

- 10 May 1959: Drought perils wheat crop in North China.
- 19 August 1959: China is believed to be coping successfully with one of the worst droughts in mainland China in several decades.
- 27 August 1959: China announced that its 1958 production figures issued earlier this year, had been overstated. It also reduced output goals set for 1959.
- 12 February 1960: Taiwan buys for $5.2 million (about 0.1 million tons) of US wheat.
- 5 July 1960: The Chinese government spurs efforts to rush irrigation equipment into drought-struck north east provinces to save wheat crop.
- 7 August 1960: The Chinese government is resorting to extraordinary measures to produce food. Millions of people are shifted from nonagricultural jobs to fight shortage.
- 16 October 1960: Several million tons of wild plants have been collected in north China against losses caused by crop failure, the Peiping radio has reported.
- 23 January 1961: In 1960 China and the Soviet Union had an “unsatisfactory agricultural output”.
- 4 May 1961: An agreement was signed between China and Canada for the sale of 6 million tons of grains (at a cost of $362 millions) over a period of 2.5 years.
- 13 September 1961: Canada is also exporting grains to the Soviet Union and Poland.
- 10 March 1977: After three years of reducing its wheat imports, China is once again diping deeply into its foreign currency reserves to feed its people. Total wheat imports reached $550 million. [At a price of $55/ton this represents 10 million tons, i.e. some 6.5% of Chinese consumption. Without such massive imports the situation might have become quite as dramatic as in 1960.]
- 20 March 1977: China’s economic performance last year was the worst since the Cultural Revolution in the late 1960’s, with the growth rates of industrial and agricultural production well below those of 1975. [According to government data, the real GDP growth rate was 8.7% in 1975 and -1.6% in 1976.]
this quantity represented 38 million tons) enough to meet US domestic needs for two years. Nevertheless, US exports to China were practically nil between 1950 and 1970.

Led by its fairly independent Prime Minister John Diefenbaker, Canada was willing to brave the embargo. It sold a small amount of wheat to China in 1958 and opened discussions with the US to get permission to sell more. Indeed, in 1961 Canada sold about 1 million tons of wheat and barley to China. This represented one third of total Chinese imports of foodgrains in 1961 (Lu 1997, p.22) but less than 1% of the total production of around 170 million tons according to SNIE (1961, p.3). It was both too little and too late. In summary, it can be said that through its own embargo and its influence on other western grain exporting countries, the United States bears at least partial responsibility in the crisis of 1960.

Conflicting accounts
Most present-day accounts blame the “Great Leap Forward” as the main cause of the food crisis. However, a US intelligence report (SNIE 1961) which was published in April 1961 gives another perspective. It is of interest for several reasons.

(1) Classified as “Secret”, this joint report of the intelligence organizations of the Army, Navy, Air Force, State Department and of the Central Intelligence Agency, was not destined to be published. Therefore, one cannot claim that it was part of a public relations operation and does not reflect the opinions of its authors. As a matter of fact, it was declassified only in December 1996.

(2) As it was published in April 1961 it is possible to check whether its predictions were confirmed by subsequent events. This test supports indeed the perspective which is presented.

(3) The SNIE report contrasts with present-day mainstream accounts in several important ways. For instance, it describes in detail the measures already taken in 1960; they show that, contrary to the claim made in the Wikipedia articles mentioned above, the leadership was well informed about the reality of the situation.

Was the “Great Leap Forward” an economic failure?
Nowadays it is a standard and almost self-evident belief that the “Great Leap Forward” (1957–1960) was a technical and economic failure. It is indeed quite likely that it put additional stress on country side people, but was it an economic failure?

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14A discrepancy can be noted between Lu (1997, p.22) and SNIE (1961, p.6) regarding the total imports of grain in 1960: the first source gives 5.81 million tons whereas the second gives 2.81 million tons. The reason of this difference is that the second number is based on contracts which had been concluded by April 1961 when this report was published. This means that there were additional contracts and deliveries between April and December 1961, probably from Burma and Malaysia.

15Though also held in China, this view is more based on ideological reasons developed during the Deng period than on hard facts.
Although only of marginal importance for the purpose of the present paper, from a scientific perspective the question certainly deserves to be raised.

The following facts can be mentioned.

- A short Internet search shows that at least 5 large dams were built in those years. Here is the list.
  (i) 1957–1960, Sanmenxia Dam, Henan/Shanxi, 106m, 16.2 cubic-km
  (ii) 1958–1962, Xinfengjiang Dam, Guangdong, 105 m, 13.9 cubic-km
  (iii) 1958–1962, Zhexi Dam, Hunan Province, 104 m, 3.65 cubic-km
  (iv) 1958–1981, Chengbihe Dam, Guangxi, 70 m, 1.12 cubic-km

In 1964, René Dumont, a French expert in agricultural economics wrote the following (Dumont 1964, p. 393, our translation): “Between 1955 and 1964 I observed the most extraordinary transformation of the agricultural landscape. When one flies over China from Hanoi to Beijing one sees that the regions to the south of the Yangtze are now covered with canals, levees and dikes”. Naturally, the other side of the coin was that for this kind of work men were often employed far away from their villages which disrupted family life and reduced conceptions. This may have amplified the Bertillon birth effect. It is a fact that birth reductions were much more pronounced south of the Yangtze than in northern provinces.

- The SNIE (1961) report gives growth estimates for industrial production and GDP which are summarized in Table A1. The forecast for 1961 was made under the assumption that Soviet technicians would not come back to China; otherwise it would have been higher.

| Year   | 1958 | 1959 | 1960 | 1961 (forecast) | Average |
|--------|------|------|------|-----------------|---------|
| Industrial production |       |      |      |                 |         |
| GDP    | 33%  | 16%  | 12%  | 20%             |         |
| GDP    | 18%  | 12%  | 8%   | 13%             |         |

Notes: It is often said that the “Great Leap Forward” was a technical failure but the present estimates made by the US intelligence community tell another story. It is true that such a rapid growth was not sustainable but the spirit of doing things notably faster than elsewhere is still present in China nowadays. The construction of the high speed rail track between Beijing and Shanghai was completed in 3-4 years, whereas in France the construction of a similar line between Lille and Montpellier (almost the same distance) took about 15 years.

Source: SNIE (1961, p.2,5) [Special National Intelligence Estimate].

Quite understandably the report does not say how these figures were computed but the fact that making such estimates was one of the main duties of US intelligence agencies suggests that they had means to do that reliably. Here again, the fact that the report was not destined to be made public is important because otherwise the publication of estimates could be a way to influence the public opinion.
Despite the slowdown of 1960-1961 the average rates remain impressive even for a fast-growth economy like China. They justify the SNIE’s observation that “Peiping recognized that it could not continue the breakneck industrialization tempo of 1958–1959”.

According to government statistics released later on, there was a decline in the GDP in 1962–1963. It is difficult to separate the after-effect of the food crisis from the consequences of the departure of the Soviet technicians, the shutdown (or reduction) of Soviet oil supply and other adverse conditions connected with the end of the Soviet economic cooperation. The end of Soviet assistance was particularly critical in the face of the continued western and Japanese trade embargo at least until 1971.

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