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The physics of large-scale food crises

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HIGHLIGHTS

- Mass mortality episodes are followed by birth troughs 9 months later.
- There is a power law relationship between death and birth amplitudes.
- It can give estimates for the death toll of major disasters.
- The method is tested on 3 case studies.

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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 therefore in subsequent births nine months later.

This scenario is studied in three cases of large-scale food crises: Finland (1868), India (1867–1907 and 1942–1944), China (1960–1961). It turns out that between the regional amplitudes of death spikes on one hand and the amplitudes of birth troughs on the other hand there is a power law relationship. This confirms the same phenomenon already observed in the wake of the epidemic of 1918 in the United States (Richmond et al., 2018b).

In the second part of the paper we explain and demonstrate on three case studies how this relationship can be used for the investigation of mass-mortality episodes in cases where direct death data are either uncertain, suspicious or nonexistent.

1. Introduction

1.1. A plea for comparative analysis

The title of the present paper[1] was inspired by a book published seven years ago [2] 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, for us in this title it is the mention of the word "physics" that was the most important source of inspiration for it means

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1 The 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 in his book entitled "The rules of sociological method" [1]. Durkheim's methodology is quite similar to the methodology of experimental physics because at the end of the 19th century physics was seen as *the* natural approach in science. Incidentally, the same comparative approach was also used in our previously published papers in biodemography (http://www.lpthe.jussieu.fr/roehner/biodemo.html).

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Table 1
Regional fragility: high population density coupled with industrial under-development.
Source: Ren kou [3].

	Population 1954 (10^6)	Population 1959 (10^6)	Percent increase	Population density 1954 (per sq-km)	Death rate 1954 (per 1000)	Death rate 1960 (per 1000)
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.

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 implement a similar agenda.

Such a comparative approach was quite common in the late 19th century; see for instance the works of Bertillon [4], Espinas [5], Bertillon [6], Durkheim [1]. One may deplore that in recent decades comparative studies of this kind (among which we do not include meta-analyzes which are something different) have become rare, mostly due to ever increasing specialization.

1.2. The Bertillon effect: From heat-wave mortality to large-scale food crises

The Bertillon effect [6–8] consists in the fact that any mass mortality is followed 9 months later by a birth rate trough.

Note that the birth rate trough is much larger (usually about 10 times larger) than the reduction in births due to the fatalities among adults of child bearing age. This was shown in detail in Richmond and Roehner [7] and can also be seen from the simple fact that excess fatalities would result in a one sided fall (with a Heaviside function shape) not in a symmetrical and fairly narrow trough. The birth trough is mostly due to a temporary reduction in the conception rate among people who are affected by the disease or food crisis but who do not die. Usually this number is much larger than the number of adult deaths.

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[2] of the order of 24% ([9, 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 pioneering analysis of *daily* birth data by Arnaud Régnier-Loilier [10,11]. The reason why heat waves display only a faint Bertillon effect is not only due to low excess mortality but also to the fact that this effect is mostly concentrated in elderly people, a segment of the population which does not contribute to birth rate changes.[3]

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 impossible to observe. It would be like a pulsar which is known to exist but is too far away and too small 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.

1.3. 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 a good position to throw new light on such episodes. How?

2 In the sense of: [(observed deaths)-(deaths in normal years)]/(deaths in normal years).

3 As already said, even 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 whose conception capacity is affected but who do not die.

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.

1.4. Outline of the paper

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 and Roehner [8].

(4) We show how to retrieve past annual birth rates from a population pyramid.

(5) Finally, we develop two examples in which mortality rates are derived from census data.

2. Part 1: Quantification of the Bertillon effect

Background information for select food crises

2.1. Starvation is only a minor cause 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,[4] 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 1.7% of the deaths. The main cause of death was typhus (43%), followed by tuberculosis (5.8%), dysentery (5.7%) and smallpox (3.0%).

• Detailed data by major causes of death for the food crisis of 1942–1944 in India are given in the thesis of Maharatna [13, p. 331]. They show that death by starvation represented only 2.1% of the deaths. The main cause of death was fever due to diseases (mainly malaria) which accounted for 34% followed by scabies (18%) and dysentery (11%).

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

2.2. Crisis of 1868 in Finland

Immediate causes such as 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 considered as an isolated event. In fact, there had been similar crises in 1833 and 1856, albeit of smaller magnitude [14, p. 24, 51]. Whereas in the 1840s the average annual death rate was around 25‰ it reached 46‰ in 1833, 34‰ in 1856 and 78‰ 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 ([14], 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 amplitude of 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 country as India the crises were not synchronous.

[4] For instance the persons shown on the cover of Davis [12]. Needless to say, the inclusion of pictures which have such an emotional content also reveals something about the agenda of the author.

2.3. 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 [15, p. 5–6]. There was also an additional food-crisis in 1942–1944. Mostly confined in Bengal, it was caused by the war and the repression of the pro-independence "Quit India" insurrection. For this famine, Maharatna [13] gives a statistical description that is more detailed than for earlier famines.

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 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 [12, 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 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 whose administration should be profitable for the stockholders of the "East India Company". In particular, this meant paying the costs of the revolt of 1857, 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.

• The food crisis of 1942–1944 in Bengal was due to special circumstances, Instead of being relieved by Churchill's War Cabinet it was made worse by blocking grain imports from other provinces[5] and from outside of India.

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.

2.4. 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: population from 588 to 646 millions and 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 [16, p. 3].

At the same time the death rate fell from 20‰ to about 10‰. It is the fall in the death rate which brought about the rapid population increase for the birth rate remained stable at around 40‰. Fig. 1 shows that even at its peak value in 1960 the death rate reaches only 25‰ [3, 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.[6] 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.

2.5. 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‰ and that the death rate peak reached 78‰. 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 explanation is under-reporting in Madras. 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 (Maharatna p. 228). This suggests that in the 1870s under-reporting may have been more serious, may be by a factor 2.

[5] For instance see the boat deny policy described in the Wikipedia article entitled "Bengal famine of 1943".

[6] According to the SNIE [16, p. 1] report discussed in Appendix: "Widespread famine does not appear to be at hand but in some provinces people are now on a bare subsistence diet".

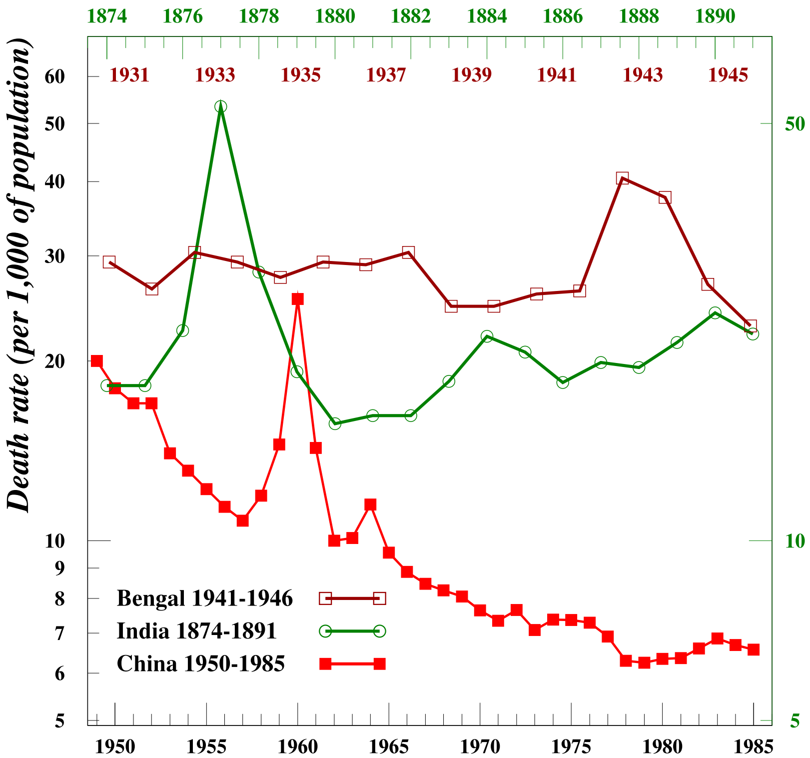


Fig. 1. Comparison of famines in India and China. The vertical scale is logarithmic and it is the same for the 3 curves but there are 3 different x-scales, each one corresponding to a specific country. As there are no nationwide data for India the curve corresponds to data for the province of Madras in the south east of India.
Source: Maharatna [13, p. 55, 228], Ren kou [3, p. 278]. The Indian data have not been corrected for under-reporting (see text).

3. 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 and Roehner [8]. 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.

3.1. Bertillon effect in Finland: Food crisis of 1868

Fig. 2 shows the Bertillon effect for the 8 provinces which composed Finland in the 1860s. The amplitude A_d of the death spike is defined as the top death rate divided by the bottom death rate and similarly for the amplitude A_b of the birth trough.

As monthly data are available for the whole country, we know that the death rate peak occurred in May 1868; therefore 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.

3.2. 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 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 and Roehner [7] 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% ($A_b = 1.06$).

[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 [13, p. 380] and [7]). In other words it is a return to equilibrium marked by an "overshooting" episode.

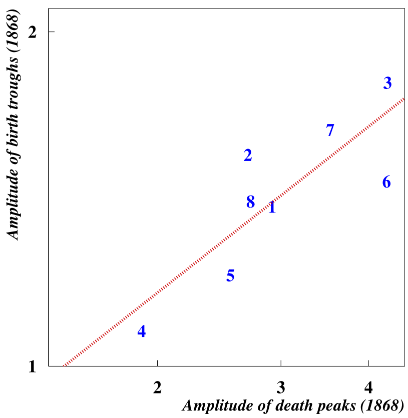


Fig. 2. Finland, 1868: relationship between the amplitudes of death spikes A_d and birth troughs A_b. The graph is a log–log plot (although this is not apparent on the y axis because the range is too narrow. Thus the straight line means that there is a power law relation between the death and birth amplitudes: $A_b = CA_d^{\alpha}$, 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 in 1868. Their names are as follows (the corresponding areas of the country are indicated with parentheses): 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).
Source: Finland [17, p. 34, XII], Finland [18, p. 274, 397].

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.

3.3. Bertillon effect in India: Analysis of annual birth and death time series

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 [19–21] and [13, 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,b show that the analysis performed in Richmond and Roehner [7] on monthly data can be repeated in a similar way with annual data.

3.4. 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.

3.5. Bertillon effect in China: Birth and death time series during 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. 5 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 700 km to the west of Hunan. The graphs show very clearly two characteristics of the Bertillon effect.

- 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

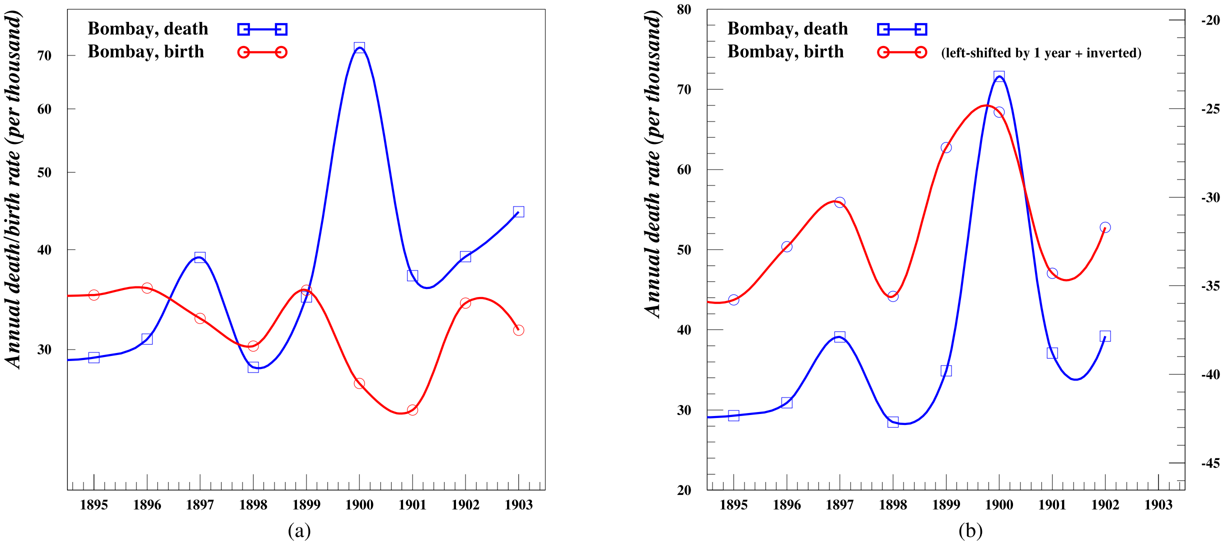


Fig. 3a,b. Annual birth and death data in Bombay (1895–1903). The difference between the left- and right-hand graph is that in the later the birth series has been shifted by one year and inverted by changing its sign. There are two food crises in the time interval 1895–1903: the one of 1896–1897 which is of small magnitude and the more serious crisis of 1899–1900. The right-hand graph makes manifest that both death spikes gave rise to a birth trough in the following year. Note that in Fig. 3a,b the *y* scale is linear to make the peaks more clearly visible.
Source: Maharatna [13, p. 55].

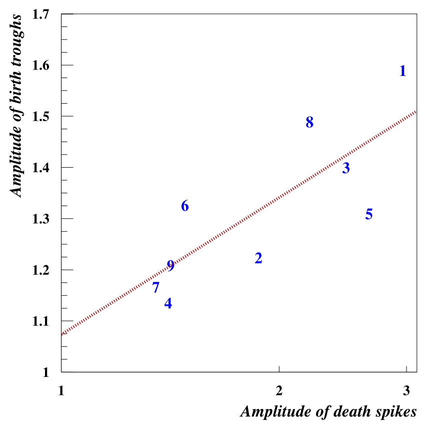


Fig. 4. India (1877–1908). Relationship between the amplitudes of death spikes and birth troughs. The relationship is as follows: $A_b = CA_d^{\alpha}$. where $\alpha = 0.30 \pm 0.16$ and $C = 1.01 \pm 0.06$. The coefficient of linear correlation is: 0.81. The correspondence between the numbers and the 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 [13, p. 55].

3.6. Bertillon effect in China: global death–birth relationship

Figs. 6a and 6b 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. 6a gives the relationship between peak and trough amplitudes. As their formation and disappearance extends over several years one may ask what is the relationship between birth decline and death increase in the years preceding and following the apex of the crisis. The results are as follows.

• In 1958 and 1959 there is no significant correlation because the deviations from the base line (i.e. the average of 1956–1958) are too small compared to the background noise.

• In 1960 the correlation and regression are almost the same as in Figs. 6a and 6b.

• In 1961 and 1962 there are significant correlations with $\alpha = 0.17,\ 0.57$ respectively.

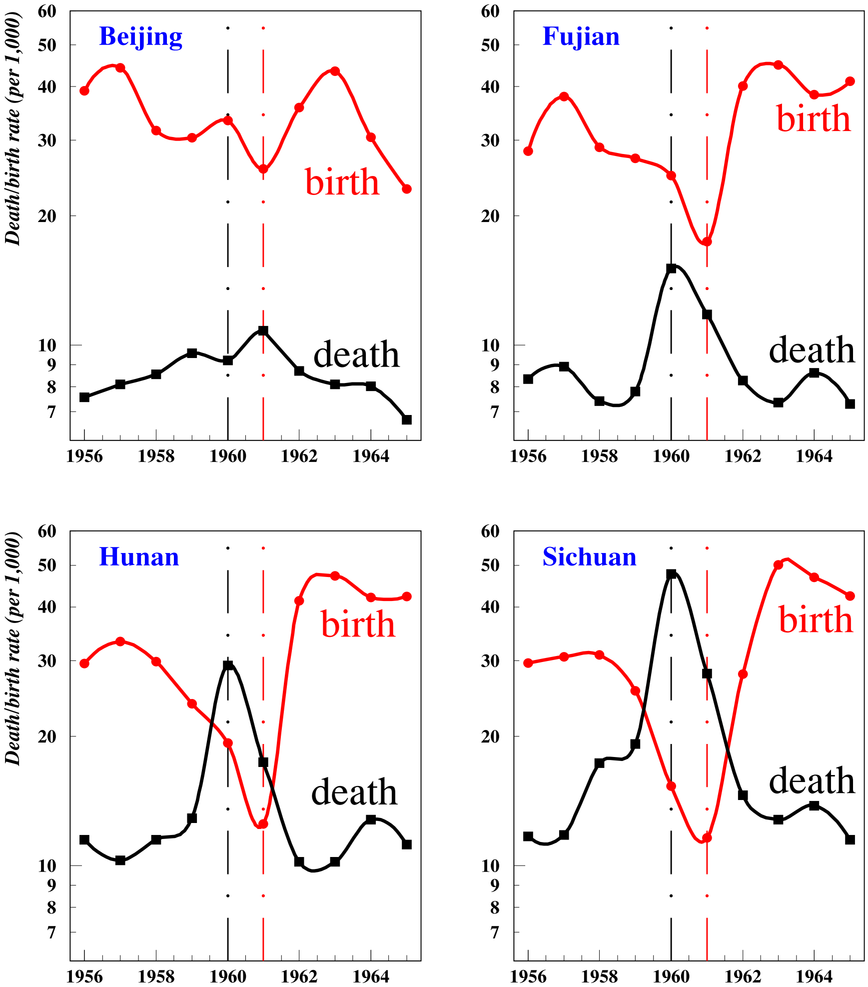


Fig. 5. Birth and death rates in 4 Chinese provinces. The curve of deaths is in black with filled squares; the curve of birth is in red with filled circles. The graphs are ranked by order of increasing severity. It can be seen that the fall of the birth rates in 1957, 1958 provide so to say early warnings of an impeding crisis. The fact that the minima of the birth troughs occur in 1961 shows that the mortality rates certainly peaked in the second half of 1960.
Source: Ren kou [3].

In summary for the three years 1960–1962, the average of α is 0.41 and the average of C is 1.18. In other words, the values given in the caption of Fig. 6a are on average also valid for the post-apex years. This rule may (tentatively) be applied whenever a crisis extends over several years.

3.7. 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 observations there is another feature 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. 6b. This kind of permanent structural fragility may have several causes (e.g. higher population density despite smaller resources) which are discussed in Table 1.

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. 6b? 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

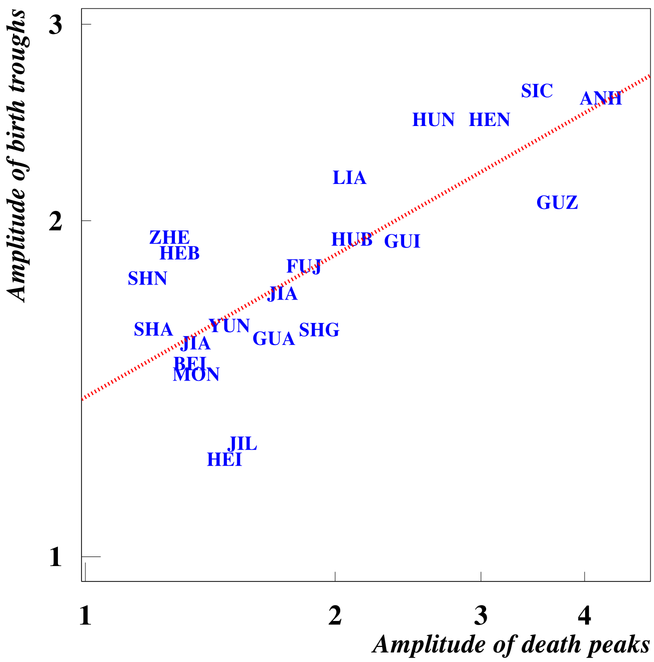


Fig. 6a. China 1959–1961. Relationship between the amplitudes of death spikes and birth troughs. It is a log–log plot. The relationship between the amplitudes of the death and birth rates is as follows: $A_b = CA_d^{\alpha}$. where $\alpha = 0.42 \pm 0.16$ and $C = 1.38 \pm 0.06$. The coefficient of 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 [3].

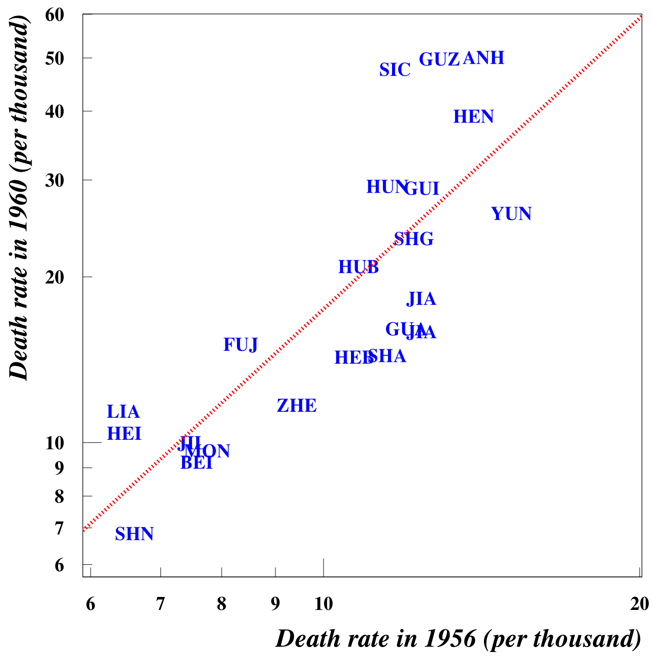


Fig. 6b. Relationship between the death rates in 1956 and in 1960 (food crisis). It is a log–log plot. The coefficient of linear correlation is: 0.81. The labels are the same as in Fig. 6a.
Source: Ren kou [3].

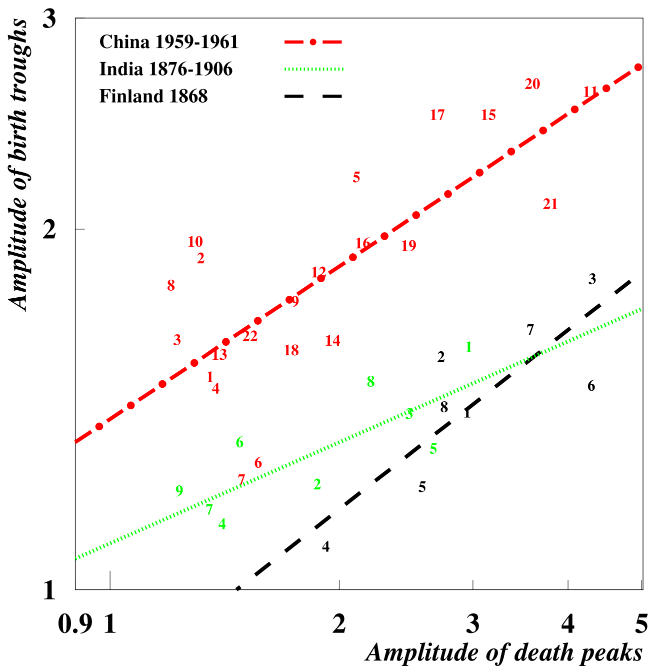


Fig. 7. Comparison of the regression lines for the three case studies. It is a log–log plot. The numbers refer to the provinces of the respective countries.

growth. However, the data in Table 1 do not show a faster population increase in Anhui–Sichuan. Even if it had 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.

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 difference in the prevalence 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 [22, 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 is to focus on general rules. In the next subsection we compare the regression lines in Finland, India and China.

3.8. Comparison of the regression parameters

When the three regression lines for $A_b = CA_d$ are drawn on the same log–log plot (see Fig. 7) one can compare their slopes (given by the exponent α) 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 in Table 2 that they are fairly similar for Finland and China but 50% smaller for India. Regarding the value of α 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 α.

For the influenza epidemic of October 1918 in the United States the slope was [8]: $\alpha = 0.19 \pm 0.1$ and $C = 1.28 \pm 0.22$. Here, a lower value of α 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 second part of the paper we will show how the death–birth relationship can be used as an exploration tool for historical mass mortality events.

Table 2
Recapitulation of the values of the exponent α.
Source: The food crises values are from the present paper; the influenza value is from Richmond and Roehner [8].

	Country and year	α
Food crises		
	Finland (1868)	0.50
	India (1877–1908)	0.30
	China (1959–1961)	0.42
	Average	0.40
Influenza epidemics		
	United States (1918)	0.19

Notes: It is fairly natural that the exponent is higher for food crises than for influenza epidemics because the later are much shorter (of the order of one month). Note that the data given in Wang and others [23] which cover the period 1980–2016 may contain other cases of food crisis particularly in developing countries. Such data can be useful for a subsequent paper.

4. Part 2: Mass mortality episodes explored through the Bertillon effect

What makes the Bertillon effect instrumental in exploring mass mortalities?

4.1. Why are mass 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 birth and death registration networks 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.

4.2. 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.

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 8b 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.

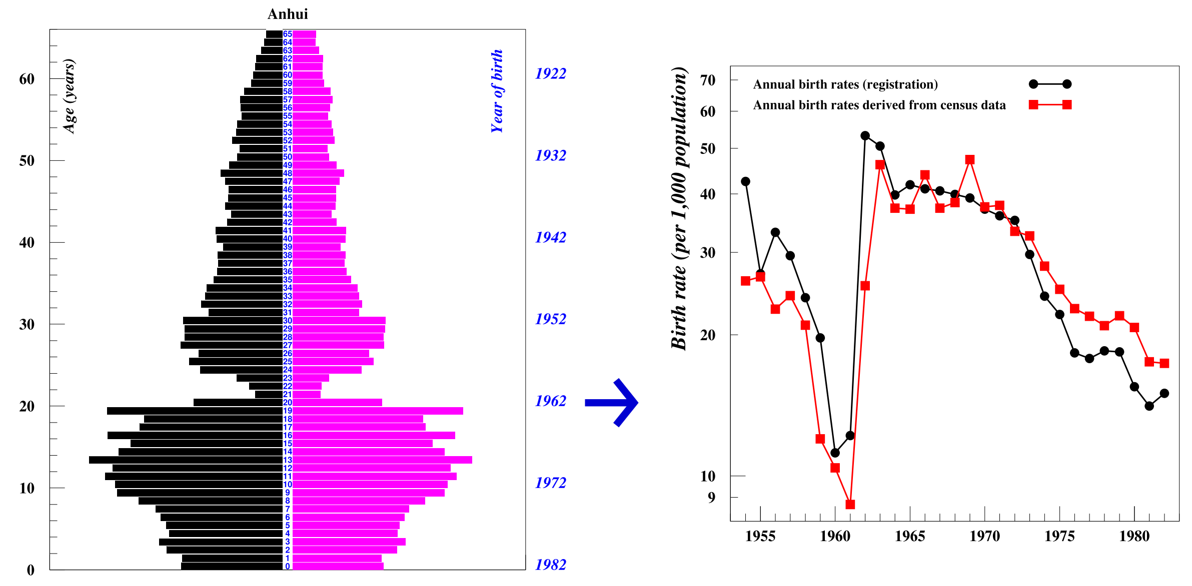
More generally, the individuals aged x in 1982 were born in $y_b = 1982 - x$. For instance, the individuals born in $y_b = 1970$ will be 12 year old in 1982. Naturally, during these 12 years some of these children died or moved from Anhui to another place (whether in China or abroad); conversely some 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 exist 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. For some reason the authorities may wish to publish under- or over-estimated death numbers.[8]

8 For instance, according to 'Résumé rétrospectif [24, 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 Prussia (27.0) England and Wales (22.5), Sweden (20.2), Denmark (19.9). Most likely, such a small rate resulted from under-reporting.



(a) (b)

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)** The y scale is logarithmic. Graph 8b 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.
Source: Population pyramid: IPUMS. Birth data: Ren kou [3].

The procedure can be represented by the following diagram:

$$\text{Census} \xrightarrow{\textit{Population pyramid}} \text{Birth data} \xrightarrow{\textit{Bertillon law}} \text{Death data}$$

5. The methodology is tested on an influenza epidemic

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).

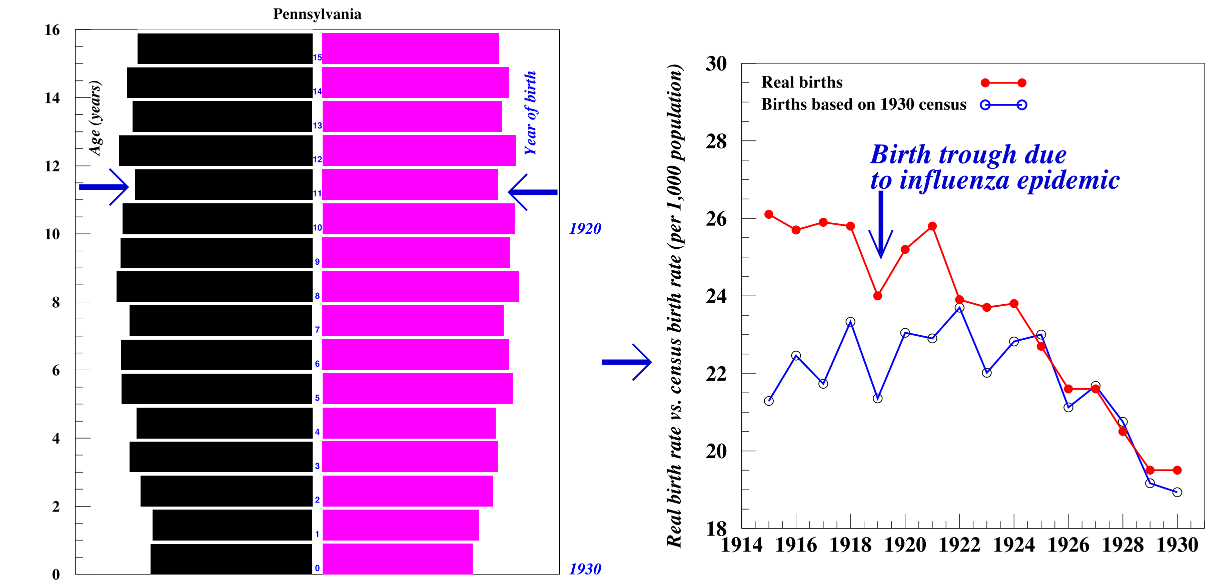
The challenge now is to see if we can derive the death peak amplitude solely from the age-group data given by the census of 1930. For that purpose we need to go through the following steps.

(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 measured with respect to adjacent values 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 $C = 1$ for the multiplicative constant. Thus, using the value of α given previously for influenza in the US (see Table 2) one gets:

$$A_b = A_d^{0.19} \quad \Rightarrow A_d = A_b^{1/0.19} = 1.09^{5.26} = 1.57$$

(3) Now, in order to derive the death rate in 1918 from the amplitude A_d 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‰ [14, p. 73]. Here, as the death rate in Pennsylvania is in fact well



(a) (b)

Fig. 9a,b. Derivation of annual census birth numbers from the population pyramid of Pennsylvania as given by the census of 1930. **(a)** The population pyramid was truncated to the ages that are required for our exploration of the birth trough of 1919 (indicated by arrows). **(b)** In this graph the curve in blue (lower curve) is identical to the population pyramid except that it was rotated by 90 degrees. The data point of the age-group 0–1 in the census of 1930 should be identical to the real births in 1930; the small difference seen in the graph is due to the statistical fluctuations resulting from the fact that the population pyramid was derived from a 5% sample of the census of 1930. As one moves back in time it is of course natural that the distance between the two curves increases because the people born in these years appear in 1930 as age-groups having suffered more losses.
Source: Population pyramid: IPUMS, Birth data: Linder and Grove [25, p. 666–667].

known (for in 1915 it was already a death registration state) we can check whether the Swedish proxy is reasonable. It is indeed correct 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.

6. Civilian mortality in Georgia during the 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.

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 1.3 as read on Fig. 10 for the year 1865 which follows the "March to the Sea".

Can the results obtained in Part 1 be used here?

At first sight it may seem that the situation of Georgia during the "Civil War" differed from a food crisis because of the military aspects. However, a closer examination reveals that food scarcity was in fact the key-factor. This is shown by the following facts.

• There was little fighting in Georgia at least until September 1863. Moreover the state governor Joseph Brown wanted Georgian troops to be used only for the defense of Georgia rather than to deploy them on other battlefronts. In other words, the husbands were rarely far away from home. Moreover, all in all there was relatively little fighting in Georgia itself. Sherman's "March to the Sea" was hardly opposed.

• Before the war Georgia was mostly growing cotton. Food normally from the Northern states. However, during the war the Union established a blockade which prevented the arrival of food. As it was easier to export the cotton by ship than to import food from the north the governor had to require farmers to grow imposed quotas of grain. Nevertheless, the food shortages worsened throughout the war, especially in cities and towns.

• During the "March to the Sea", Sherman's troops burned plantations, wrecked railroads, killed livestock and lived off the land. They confiscated 5000 tons of corn and about the same amount of fodder. The destruction of the transportation infrastructure hindered shipments of basic necessities to urban areas.

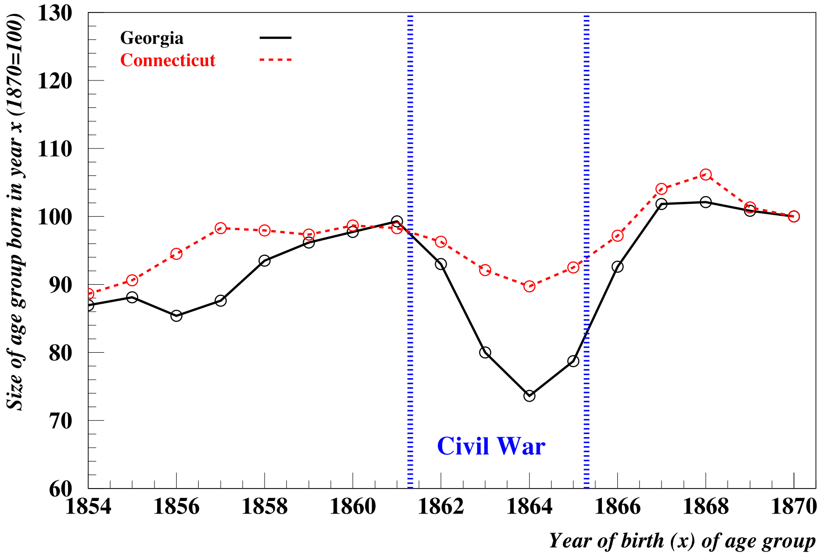


Fig. 10. Population "pyramid" in Georgia and Virginia (rotated by 90 degrees). Instead of showing the age as is most common for a population pyramid the horizontal axis shows the year of birth. The fact that in 1861 (i.e. persons born before the Civil War) and 1870 (i.e. persons born several years after the Civil War) the levels are nearly the same shows that there was no net and permanent emigration or immigration in this time interval [26,27].
Source: 1% sample of the census of 1870 from the database of IPUMS, USA.

The comparison with Connecticut shows that birth reductions due to military enrollment (e.g. husbands far away from home) were rather limited.

In other words, the main aspect of the Civil War in Georgia is the fact that it put the state into a food crisis situation.

The relationship between birth troughs and death peaks can be written: peak amplitude $A_d \simeq A_b^{1/\alpha}$. Based on the estimates found in Part 1 we take $\alpha = 0.4$ which gives: $A_d = 1.22^{2.5} = 1.64$.

For the average death rate in 1861–1870 we take the rate of Sweden namely 20‰ [24, p. 368]. Thus, the peak rate in 1865 was: $1.64 \times 20 = 32.8$‰. In 1860 the population of Georgia was about 1 million; this leads to an excess-death toll (ED) of $\text{ED}(1964) = (32.8 - 20) \times 1000 = 12{,}900$.

This calculation can be repeated for the other years.[9] One gets:

$A_b(1863) = 1.26 \longrightarrow \text{ED}(1862) = 14{,}210$
$A_b(1864) = 1.33 \longrightarrow \text{ED}(1863) = 20{,}000$
$A_b(1865) = 1.22 \longrightarrow \text{ED}(1864) = 12{,}900$ (March to the Sea)
$A_b(1866) = 1.09 \longrightarrow \text{ED}(1865) = 4810$

Altogether, we get the following civilian excess-death in Georgia: $\text{ED}(1862\text{–}1865) = 51{,}920$. It represents 2.8 times the number of the Georgian military deaths (namely 18,253).

7. Magnitude of the Fiji measles epidemic of 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 [28, p. 8]. Note that both the population and the death toll are merely estimates made by western visitors.[10]

There will be three parts in this investigation.

(1) Firstly, we apply to the epidemic of 1875 the birth–death methodology previously used for Pennsylvania and Georgia. It leads us to the conclusion that the death toll attributed to the measles epidemic was probably vastly exaggerated.

(2) We describe additional facts and data which support the previous conclusion.

(3) We try to understand what may have motivated contemporary authors to over-emphasize and over-estimate the death toll.

7.1. Is the 33% death toll compatible with subsequent birth numbers?

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.

9 For an index y the excess death ED is given by: $\text{ED} = 20{,}000(y^{1/\alpha} - 1)$.

10 For instance, the population estimates published by different visitors range from 100,000 to 300,000.

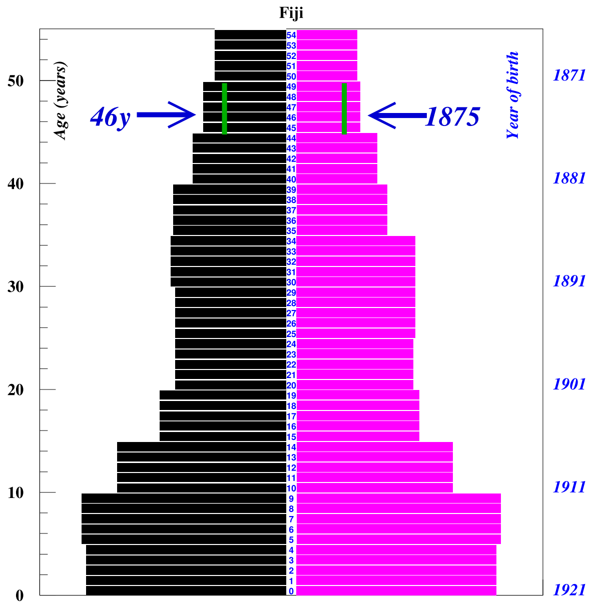


Fig. 11. Was there a devastating measles epidemic in Fiji in 1875? The ages given on the left-hand side correspond to age-groups in the census of 1921. The expected birth troughs of 1875–1876 will be seen in the census of 1921 as a reduced age-group for the age: 1921−1875=46y. Based on a death–birth relationship with an exponent $\alpha = 0.2$, 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 [28, p. 38].

Even without doing any further calculation a comparison with Anhui where the death toll in 1960 was 5% (3, p. 280, this rate includes the normal death rate of about 1.5%) 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, the calculation involves the following steps.

(i) Computation of the amplitude of the death spike based on the 33% annual death toll.

(ii) Computation of the amplitude of the subsequent birth trough based on the death–birth relationship. For α we selected $\alpha = 0.2$ that is to say similar to the influenza case of 1918 in the US (Table 2). However, taking another value (e.g. $\alpha = 0.3$) would make little difference.

(iii) Finally, from the amplitude of the birth trough one derives the death amplitude A_d and the expected contraction of the corresponding 5-year age group (shown in green in Fig. 11).

One sees that a death toll of the claimed amplitude of 33% would lead to a deeper indentation than actually observed.

7.2. Additional evidence about measles incidence and death rates

The previous calculation may fail to convince readers because it necessitated a number of assumptions, for instance the value of α. It may be more straightforward to compare directly the Fiji epidemic to similar cases. The following facts provide elements for such a comparative perspective.

(1) First, one should observe that the Fiji islanders have been in contact with European and American traders and missionaries since the beginning of the 19th century: According to McArthur, first came sandalwood traders, then around 1830 sea cucumbers (a kind of sea worm) traders. Missioners started to arrive in 1835 and white settlers came in their wake. During the American Civil War there was a rush of settlers who developed a lucrative cotton trade. In other words, in 1875 the organisms of the islanders have been in contact with foreign infectious diseases for at least two generations, a time span during which no major epidemics were reported. More specifically the presence of western permanent residents (settlers, missionaries) with families and *children* must have brought at least some of the natives into contact with the measles virus.

(2) In spite of the fact that a vaccine was only developed much later (in the 1960s), in all European and American countries for which data are available the death rate of measles was of the order of 0.1‰ that is to say very low. For instance in 1910 it was 0.2‰ in Germany, and 0.1‰ in France and Michigan; moreover it did not show any large epidemic fluctuations [29, p. 451–541].

(3) In fact, for the epidemic of 1875, British sources do not give death statistics but only statements. There are two main contemporary sources, namely: Corney [30, p. 84] and Corney et al. [31, p.36]

The first reads:

> "I regret that I am not able to lay before you the complete statistics of the mortality. I believe they have not been published *in extenso*. But "no less than 40,000" are the words given by Sir Arthur Gordon [British Governor of Fiji from 1875 to 1880.] in an official dispatch to the Secretary of State as the total number of deaths resulting from the epidemic."

The second reads:

> "It is recorded, probably with fair exactitude, that 40,000 died from measles during the epidemic which overran the archipelago in the space of 4 months [from February to May]."

(4) It is true that Bolton Corney gives data for three small islands of the archipelago, namely for Ovalau, Koro (Corney 1883) and Rotuma [32], this Rotuma epidemic occurred in 1911), in which the death rate reached 28%. However these were small islands with populations of less than 2500 as compared with 150,000 for the whole archipelago. It is possible that in such small groups the population was more genetically homogeneous which may explain the high death rate. However, there may also be another explanation. As on these isolated islands there was no colonial surgeon or anybody else able to issue death certificates one can only say that there was a sudden fall in population within a few months but whose cause remains unknown.

7.3. Measles as a screen for other causes of death

What raises suspicion about the accounts given by Bolton Corney is the fact that there were major causes of death that are just ignored.

A quick picture of the process through which western colonists took possession of the land in Fiji can be gained by saying that it was similar to what happened in Hawaii or in California; this last case was described in detail by Benjamin Madley [33].

The rising price of cotton during the American Civil War (1861–1865) saw a flood of hundreds of settlers come to Fiji from Britain, Australia and the United States in order to obtain land and grow cotton. By the end of 1870, there were around 2500 white settlers in Fiji. As in Hawaii a constitutional monarchy (largely under western control) was established. In 1872 conflicts between natives and groups of vigilantes set up by the settlers resulted in natives being shot and villages burned particularly in the eastern part of Viti Levu which is the main island (some 150 km in diameter).

From March to October 1873, a force under British consul Robert Swanston (the son of an Australian banker) comprising 1000 coastal Fijians plus white volunteers conducted an annihilation campaign against highland natives. Some were hanged and the rest sold into slavery and forced to work on plantations throughout the islands.

From late 1875 to the end of 1876 a similar campaign was conducted in the western part of Viti Levu under a scorched earth policy whereby numerous rebel villages were burnt and their fields ransacked.[11]

Ransacked fields necessarily led to food crises. Moreover, just as in California, the fact that men became separated from their wives resulted in reduced birth numbers.

Why did such tragic events not translate into deeper birth rate indentations in the population pyramid of Fig. 11? The reason is certainly because the hardships (and related excess mortality) were not concentrated on one or two years but instead were spread over a period ranging from 1860 up to 1876. Moreover, at the census of 1921 the persons born between 1860 and 1876 were over 45 year old; as a result these age groups were small and cannot give accurate evidence about their changes.

Then 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. In subsequent years the Indian community developed to the point of becoming larger than the native Fijian population which created many problems.

In short, our thesis is that the toll of the measles epidemic of 1875 was grossly over-estimated in order to account for the brutal fall in the native population revealed by the census of 1879.

8. Conclusion

8.1. Outline of the exploration of food crises

In his seminal paper Jacques Bertillon used weekly and monthly birth and death data [6]. 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 effect were found to be compatible with the 9-month time lag revealed by weekly and monthly data.

By observing regional death peaks and birth troughs, we found a power law relationship between their respective amplitudes in confirmation of a similar relationship already observed in Richmond and Roehner [8].

[11] The main source is a two-volume account published by the British governor Arthur Gordon [34]. Although certainly sanitized, the account makes no mystery of the methods that were employed. For instance, on p. 464 one reads "There was a great deal of burning down in the south but in the circumstances that was unavoidable".

8.2. Agenda for future explorations of mass mortality episodes

The spirit of a death registration network is to go bottom up. Starting from town and countryside level one should move up to county, state and nation level. At each step the death numbers should be aggregated until one gets a total number for the whole country. Any death estimate made at the macro-level without being supported by appropriate data at lower levels 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. 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 mistakes.[12] 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 study more than just one case and 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 statistics because such figures are published by the two trade partners, as exports on one side and as imports on the other side. It is the purpose of the present appendix to present a number of additional data of that kind.

A.1. Parallel with the food crises of 1878 and 1977

Food crises were fairly common in Qing and Kuomintang China. However, from our perspective there are two crises which were of particular interest, namely the one of 1876–1878 and the one of 1977. The first is interesting because it was very similar to the one of 1960–1961 and the second because it also occurred under similar meteorological conditions but much later.

An article entitled "La famine en Chine" [Famine in China] was published in 1880 in a French scientific journal [35] which describes a meteorological situation very similar to the one observed in 1959–1960, namely a severe drought in north China which lasted over 3 years together with flooding 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 flooding.

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 [36,37]. 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.

In 1977 there was another wheat crisis which did not translate into a food crisis only because at that time the US embargo had been lifted which allowed massive grain imports of 10 million tons, that is to say some 6% of Chinese consumption.

A.2. 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.[13] 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.

A.3. Wheat imports

The situation was aggravated by the difficulties and delays in importing grains. The United States enforced a strict embargo and the USSR was unable to export grains to China.[14] A table of the SNIE [16] reports that there were no Soviet grain

[12] Such as the claim that China did not import grains before 1962 which, as will be seen below, is not correct.

[13] 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.

[14] What is the most surprising in western accounts (e.g. Wikipedia) is the claim that the Chinese government did little to come to the help of the population. Actually, as shown by the following articles published in the "New York Times", there was a intense national mobilization. It is also often claimed that the grain statistics were unrealistic, but the excerpt of August 1959 shows that previous data were revised whenever they were found over-estimated.

exports to China. Soviet–China relations already started to sour in 1960. In July–August 1960 the USSR abruptly withdrew nearly all of the 2500 Soviet industrial technicians present in China; moreover, a disruption in oil delivery created a shortage of petroleum products in late 1960 [16, 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 30 kg 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 17% of total Chinese grain imports in 1961 ([38, p. 22]) but less than 1% of the total production of around 170 million tons according to SNIE [16, p. 3]. It was both too little and too late.[15]

In summary, it can be said that through its embargo and its influence on other western grain exporting countries, the United States bears partial responsibility in the crisis of 1960.

A.4. Conflicting accounts

Most present-day accounts blame the "Great Leap Forward" as the main cause of the food crisis. However, a US intelligence report [16] 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 say that it was part of a public relations operation. 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.

A.5. 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.[16] It is indeed quite likely that it put additional stress on countryside people, but was it an economic failure? 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.

• An 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, 106 m, 16.2 cubic-km

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• 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 non-agricultural 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 [i.e. Beijing] 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 dipping 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.]

The broad national mobilization documented by the NYT is consistent with expectation based on recurrent events for during all the Civil War there were closed links between the people, the armed forces and the leadership.

15 A discrepancy can be noted between Lu [38, p. 22] and SNIE [16, p. 6] regarding the total contracts for grain imports in 1961: 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 figure is based on contracts which had been concluded before 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.

16 Though also held in China, this view is more based on ideological reasons developed during the Deng period than on hard facts.

Table A.1
Estimates for industrial production and GDP growth during the "Great Leap Forward".
Source: SNIE [16, p. 2, 5] [Special National Intelligence Estimate].

	1958	1959	1960	1961 (forecast)	Average
Industrial production		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 Montpelier (almost the same distance) took about 15 years.

(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 (39, 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 [16] report gives growth estimates for industrial production and GDP which are summarized in Table A.1. The forecast for 1961 was made under the assumption that Soviet technicians would not come back to China; otherwise it would have been higher.

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 Soviet economic cooperation. The end of Soviet assistance was particularly critical in the face of continued western and Japanese trade embargo.

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