Childhood Sex Ratios as Indicators of Infant Mortality in Historical Populations

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Abstract

We present a novel indicator of infant mortality: childhood sex ratios. Girls are hardier than boys, with lower rates of infant mortality unless their biological advantage is offset by sex discrimination. Therefore, high levels of infant mortality tend to skew the surviving population toward females. Extremes of male-biased sex ratios are familiar as indicators of missing women, but the potential for sex-ratio data to inform infant mortality estimates has gone largely unnoticed. We document the relationship between infant mortality and childhood sex ratios in historical data from Europe and its settler colonies, showing that broad patterns of infant mortality can be inferred from sex-ratio data. Widely available from census data, childhood sex ratios can shed new light on infant mortality and maternal health in populations lacking mortality data.

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1 Introduction and Background

Infant mortality—the proportion of children who die before the age of 1—is a key indicator of population health and living standards (OECD and WHO 2020; Reidpath and Allotey 2003), as well as a driving force in demographic dynamics (Coale 1989). However, broad patterns of infant mortality are largely unknown for most of the world before the mid-20th century, due to a lack of vital statistics data. For populations with incomplete mortality data, life-table methods have offered important insights on infant mortality.[1] But for populations without mortality data, estimating infant mortality has been an intractable problem—until now. We offer a new approach: using childhood sex ratios to infer infant mortality.[2]

Biologically, boys are more vulnerable than girls to infant mortality.[3] The corollary which we highlight, and build from, is that high rates of infant mortality tend to skew childhood sex ratios toward females, absent extremes of sex discrimination (see below). If a population has very low infant mortality, say 5 per 1000 like Canada in 2018 (Statistics Canada 2022), the relative numbers of boys and girls during childhood will be nearly the same as it was at birth.[4] If, on the other hand, a population has an infant mortality rate of 200 per 1000, as was common in 19th-century Europe, then the observed sex ratio during childhood will be distinctly more female than it was at birth.

While under-appreciated to date, the relationship between infant mortality and childhood sex ratios is a standard feature in well-known demographic models.[5] For example, in the widely-used Coale-Demeny West model life tables, as infant mortality increases from 27 to 160 per 1000, the under-5 sex ratio moves 2 percentage points toward girls (Coale and Demeny 1983:47, 52).[6]

[1] For example, see the infant mortality rates in the life tables constructed by Haines (1998) and Hacker (2010) for the 19th-century USA.

[2] *Childhood sex ratio* refers to the relative number of girls and boys in a population.

[3] Knowledge of excess male infant mortality dates back at least to the 18th century, for example, Struyck (1740), Wargentin (1755) and Clarke (1786); for discussion, see Théré and Rohrbasser (2006). Male infant mortality is typically 15–30% greater than that of females (Alkema et al. 2014; Drevenstedt et al. 2008). The female survival advantage in infancy is due to multiple factors: females have fewer congenital diseases owing to their redundant X chromosome, and they are also more resistant to infectious disease. For an authoritative review see Waldron (1998:64–83). Other key contributions include Waldron (1983), Kraemer (2000), and Wells (2000).

[4] In a healthy population, there are typically 5–6% more males born than female (Grech et al. 2002; Maconochie and Roman 1997).

[5] This relationship has been highlighted in efforts to detect excess female mortality. See, for example, Beltrán Tapia and Raftakis (2021), particularly figure 2.

[6] The log-change of the sex ratio follows from the ${}_5L_0$ values by sex, moving from level 22 to level 11, holding the sex ratio at birth constant. The same pattern is evident in a wide range of other life tables, including the UN model life tables.

The effect of infant mortality on childhood sex ratios is likely to be compounded by a female-tilt to the sex ratio at birth. A growing body of research demonstrates that insults to maternal well-being push the sex ratio at birth toward females (Almond and Edlund 2007; Catalano 2003; Fukuda et al. 1998).[7] As maternal health and infant mortality are closely related (Kramer 1987), populations with high infant mortality are likely to have female-skewed sex ratios at birth.

The biological vulnerability of males makes childhood sex ratios potential indicators of infant mortality.[8] However, male-biased sex ratios are familiar (in social science research and popular media) as evidence of missing women and the social vulnerability of girls (e.g. Coale 1991; Kaul 1912; Klasen 1994; Klasen and Wink 2002, 2003; Sen 1990, 1992; Visaria 1969; Zeng et al. 1993). Extremes of sex discrimination in the allocation of care, resources and nutrition eliminate the biological advantage of girls (e.g. Barcellos et al. 2014; Chen et al. 1981; Das Gupta 1987). In such cases, high levels of infant mortality will not push childhood sex ratios toward females. Instead, excess female mortality will result in male-biased sex ratios regardless of the level of infant mortality. That said, because societal sex discrimination operates against girls, not boys, female-skewed sex ratios are an unambiguous sign of high infant mortality and maternal distress.

2 Data

In order to demonstrate that infant mortality can be inferred from childhood sex ratios, we assemble credible historical data from vital statistics and censuses. Our sample covers most of Europe, North America, and the non-indigenous populations of Australia, New Zealand and South Africa, roughly spanning 1870–1970.[9] We end our series in the early 1970s; by then infant mortality in our sample populations was low enough that patterns of sex ratio variation were largely independent of infant mortality, and ultrasound was not yet a factor in sex-ratio patterns (Campbell 2013).

[7]The apparent mechanism is maternal stress hormones, which increase the probability of miscarriages, which are disproportionately male (James and Grech 2017:51). Recent work in health economics has used the sex ratio at birth as an indicator of fetal loss (Sanders and Stoecker 2015; Valente 2015).

[8]We draw on Thompson's (2021:467) apt formulation: "boys are more biologically vulnerable and girls more socially vulnerable."

[9]Our data cover: Australia (1880–1971), Austria (1869–1971), Belgium (1846–1970), Switzerland (1880–1970), Denmark (1840–1970), Finland (1885–1970), France (1901–1968), Scotland (1861–1970), England and Wales (1851–1971), Italy (1911–1971), New Zealand (1867–1971), the Netherlands (1859–1970), Norway (1890–1970), Germany (1880–1971), South Africa (1918–1921), and Sweden (1860–1970). For the USA, we have Massachusetts (1865–1915), a subset of states (1920–1930), and the USA as a whole (1940–1970). See section 7.2 for details.

For each country, we have annual infant mortality, and population by age and sex at various intervals. For a given year, we calculate the under-5 sex ratio, $U5 = log(\frac{females}{males})$, for children age 0–4. We pair this sex ratio with the 5-year rolling mean of infant mortality. We use the under-5 sex ratio for several reasons: it is widely available in published census data; pooling the under-5 population increases the sample sizes;[10] and pooling across ages reduces the impact of sex-biased age heaping.

3 Results

Figure 1 plots infant mortality against under-5 sex ratios. The empirical relationship is striking: looking from left to right, as the sex ratio moves toward girls, infant mortality climbs. Infant mortality and the under-5 sex ratio are highly correlated ($\rho = .87$) within our sample, and populations with low infant mortality tend to have some 4–6% more boys than girls, values close to the sex ratio at birth in a healthy population.

We fit a median bivariate regression with infant mortality as the dependent variable and the under-5 sex ratio as the independent variable, and plot this line in Figure 1.[11] Our fitted relationship is $\hat{IMR} = 190 + 3221 \cdot U5$.[12] Based on our regression, we would predict infant mortality to be about 65 points (per 1000) higher when the under-5 sex ratio is 2 percentage points more female, and that with equal numbers of boys and girls infant mortality would be just under 200 (per 1000).

Our goal is to infer infant mortality from sex-ratio data. To quantify the uncertainty in such inferences, we use out-of-sample testing. We drop the observations from one country, regress infant mortality on sex ratios in the remaining data, and then predict the infant mortality for the dropped observations.[13] The 80% prediction interval from these errors is just under ±40 points (per 1000), plotted in Figure 1.[14]

[10] Random variation in sex ratios will not be small unless populations are large. To illustrate, model the sex proportion as binomial random variable, as in Visaria (1967:33), with mean 1/2. With 10,000 children, the 90% CI is 6 percentage points, which is very large relative to the effects we seek to measure. With 50,000 children, the 90% CI shrinks to about 3 percentage points.

[11] We use median regression because it is less sensitive to outliers than least-squares (Koenker and Hallock 2001). Using least squares yields similar results.

[12] $N = 241$. Out of concern for measurement error in both variables, we also run the reverse regression of sex ratios on infant mortality. We obtain similar results, with $\hat{IMR} = 211 + 3961 \cdot U5$.

[13] This is a slight modification of the *cross validation* approach proposed by Butler and Rothman (1980); more recent literature refers to this as a *jackknife* (Barber et al. 2021).

[14] The precise values are $(-39.7, +37.7)$.

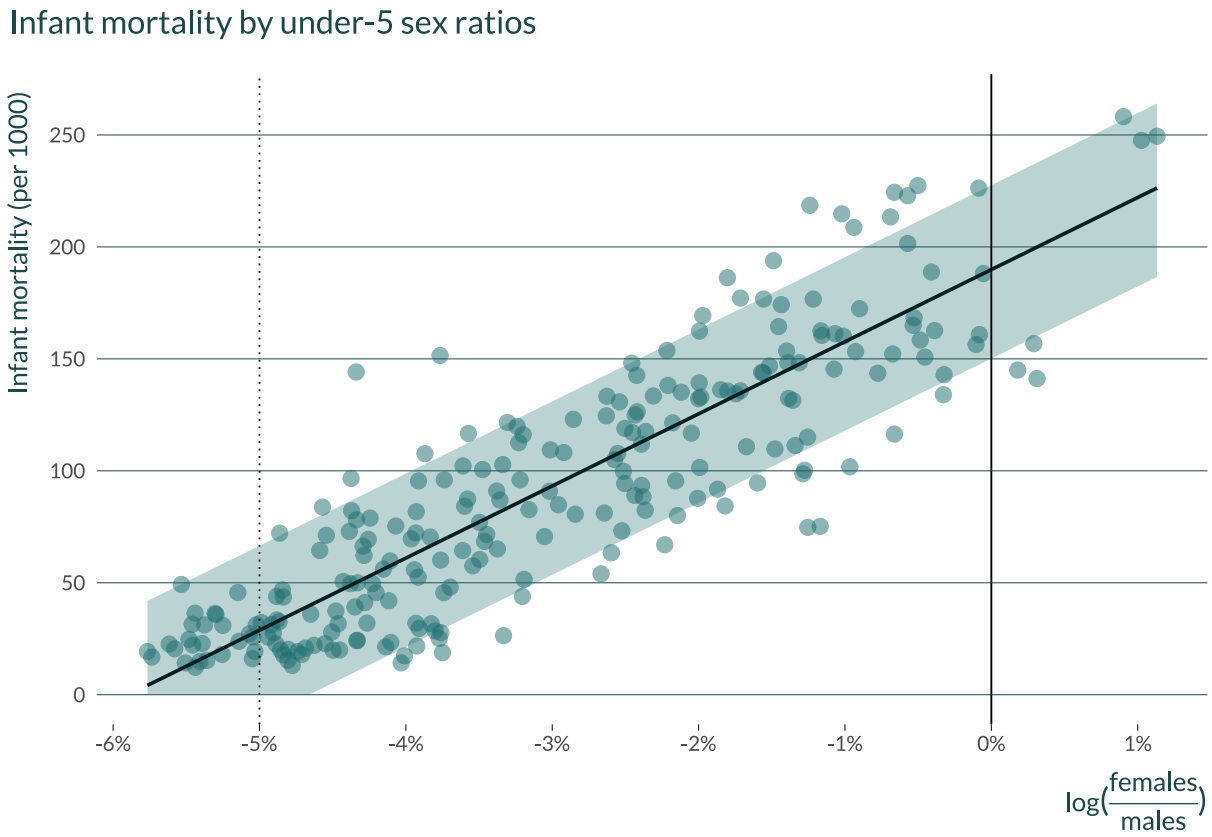

Figure 1: Infant mortality rate by under-5 sex ratios. The black line is the (median) regression of infant mortality on the under-5 sex ratio. The translucent ribbon is the 80% prediction interval, estimated by out-of-sample testing. The dotted line is a healthy sex ratio at birth of 5% more males than females. Data from Europe and settler colonies.

Figure 2 plots the relative prediction error, $log(\frac{Actual}{Predicted})$, against infant mortality. In relative terms, our predictions are more precise with greater infant mortality, while in absolute terms, they are roughly constant. This makes childhood sex ratios most informative in historical situations where a wide range of high infant mortality values are plausible.[15]

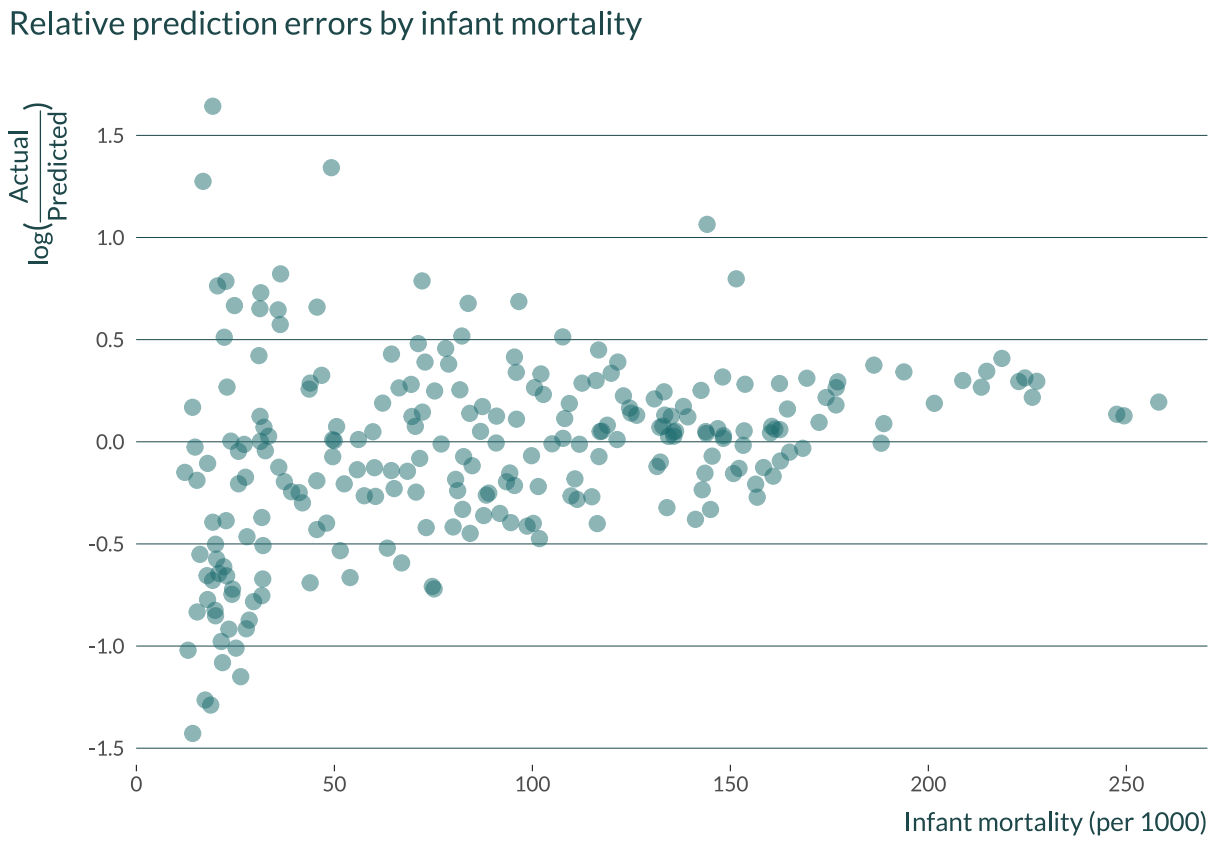

Figure 2: Relative prediction errors, log(Actual/Predicted), by infant mortality. Prediction errors calculated by out-of-sample testing. Data from Europe and settler colonies.

4 Discussion

Our results show that childhood sex ratios can reveal broad patterns of infant mortality. But our predictions of infant mortality from sex ratios are not precise; for example, even the two-thirds prediction interval is nearly ±30 points (per 1000). The uncertainty in our predictions stems from a number of factors: most simply, random variation in sex ratios and measurement error in both variables. However, we should also expect systematic differences

[15]For example, in 19th-century Europe, infant mortality ranged from 100 in Norway to 250 in Austria.

across populations in the relationship between infant mortality and childhood sex ratios.[16] When the cause of infant mortality is closely related to maternal health, for example maternal malnutrition (Kramer 1987), the effect of infant mortality on childhood sex ratios will be reinforced by a female-tilt to the sex ratio at birth. There will be no such effect if the cause of infant mortality is unrelated to maternal health, for example a low incidence of breastfeeding.[17] In addition, excess male mortality tends to vary across populations (Drevenstedt et al. 2008). Therefore, we can expect different childhood sex ratios for populations with the same infant mortality. Despite this variation, our results show that childhood sex ratios have the potential to identify plausible ranges of infant mortality.

As an illustration of the power of sex ratios to reveal infant mortality, consider South Africa in the early-20th century. Vital statistics data indicate an infant mortality rate of some 90 per 1000 for the "white" population circa 1910 (IHS 2013:219). No such statistics were collected for non-white South Africans, but the 1911 census reported population by age and sex and race. For children under the age of 5, there were 6.5% more girls than boys among the non-white population, and 3.1% more boys than girls among whites (Union of South Africa 1912:130–131). This 9.6 percentage-point gap between sex-ratio values suggests a staggering gulf between the two populations in terms of maternal-infant health. As much as 2 percentage points of the gap could be attributed to a difference in the sex ratio at birth between the two groups.[18] The remaining 7.6 percentage-point gap suggests an infant mortality rate of nearly 340 among the non-white population.[19] These values are outside the domain and range of our sample, so the precise result should be treated with caution, but such a female-skewed child population is a powerful indicator of high infant mortality and maternal distress.[20]

[16]The relationship between childhood sex ratios and infant mortality can be modeled as: $CSR \approx SRB + \mu \cdot q$, where CSR and SRB are the (log) childhood sex ratio and sex ratio at birth, q is infant mortality, and μ is excess male mortality. See section 7.1 for the derivation.

[17]Breastfeeding can have huge impacts on infant mortality (Sankar et al. 2015; Wray 1978), but need not be related to maternal health. See for example, Knodel and Van de Walle (1967) on breastfeeding and infant mortality in 19th-century Germany.

[18]The sex ratio at birth in sub-Saharan African populations tends to be about 2 percentage points more female than in most other populations Klasen (1994:1062). Morse and Luke (2021) argue that this difference reflects maternal health and fetal loss.

[19]We use the slope from our regression to extrapolate from the white infant mortality to an estimated non-white infant mortality. Our finding of a large racial gap in infant mortality is consistent with Mpeta, Fourie, and Inwood's (2018: figure 6) evidence of much smaller stature among black than white men in South Africa in the early twentieth century; both suggest early origins for South Africa's extreme racial inequality. Our finding of very high infant mortality for non-whites contradicts Nattrass and Seekings' (2011:521) conjecture that "deep poverty was probably generally limited to episodes of drought or disease" in the period 1910–1932.

[20]Marco-Gracia and Fourie (2021) argue that the female-skewed childhood sex ratios of non-white South Africans reflect discrimination against young boys. We view high infant mortality and poor maternal health as more plausible explanations.

The South African example illustrates the effectiveness of our approach— sex-ratio evidence can offer new insights on infant mortality and maternal health. However, childhood sex ratios will be a misleading indicator of infant mortality in populations where sex discrimination is extreme enough to offset the biological survival advantage of infant girls. Such populations could have healthy-looking childhood sex ratios despite high infant mortality. This possibility—a false positive in a test for low infant mortality—must be considered in applications of our approach.

Consider, for example, the Punjab in 1911, where the Census of India reported 6% more boys than girls under the age of 5 (Kaul 1912b:46)—a value which suggests a healthy population. However, both contemporary and modern scholarship make it clear that this preponderance of boys was due to sex discrimination against girls and not to low infant mortality. Visaria (1969:3) notes that the Punjab sex ratios have, historically, been among the most male-biased in India. Kaul (1912a:230–231) attributed this "disparity of the sexes" to the "neglect of female infants", a finding mirrored in the modern literature on sex-biased allocation of household resources (Das Gupta 1987). Indeed, sex discrimination in the Punjab is evident from the 1911 census data, as older sex ratios are increasingly male-biased. With 6% more boys than girls under age 5, there were 16% more boys in ages 5 to 10, and 34% more in ages 10 to 15 (Kaul 1912b:46).

5 Conclusion

Childhood sex ratios can reveal broad patterns of infant mortality. Because girls are hardier than boys, high infant mortality is reflected in female-skewed childhood sex ratios, unless the biological advantage of females is offset by sex discrimination. Assembling historical data from vital statistics, we have shown that infant mortality can be inferred from sex-ratio data, and quantified the uncertainty in such inferences. Childhood sex ratios, widely available from censuses, can offer new insights on health and well-being in populations lacking mortality data.[21]

[21] Our ongoing work involves using childhood sex ratios as indicators of infant mortality and maternal health in the USA and Canada before 1920, 19th-century France, and 19th-century Ireland and Great Britain.

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7 Appendix

7.1 Modeling Childhood Sex Ratios

To identify the systematic relationship linking childhood sex ratios and the infant mortality rate, we model the sex ratio of the survivors of infant mortality in a hypothetical population. For this simple modeling exercise, we ignore separation factors and the fact that we observe age intervals in census data.[22] Let F and M be the number of females and males born, and q^f and q^m be the sex-specific infant mortality rates. Male survivors of infant mortality will be given by $M \cdot (1 - q^m)$ and female by $F \cdot (1 - q^f)$. The (log) sex ratio of surviving children is then given by:

$$CSR = log(\frac{F \cdot (1 - q^f)}{M \cdot (1 - q^m)}) \implies CSR = log(\frac{F}{M}) + log(1 - q^f) - log(1 - q^m)$$

Using Taylor series approximation ($log(1 + x) \approx x$ when x is small), we obtain:

$$CSR \approx log(\frac{F}{M}) + q^m - q^f$$

.

For notation sake, let $SRB \coloneqq log(\frac{F}{M})$ and q be overall infant mortality. We define $\mu \coloneqq \frac{q^m - q^f}{q}$ as a measure of excess male mortality. The above expression can be re-written as:

$$CSR \approx SRB + \mu \cdot q$$

[22] In life table terms, we are modeling ${}_0l_1$ but we use observations of ${}_0L_5$.

7.2 Data Sources

The *Human Mortality Database* provides original data and access to other sources for infant mortality rates and under-five sex ratios for many historical populations. We expand our geographic scope by also drawing on vital statistics and census data from various official sources for populations not included in the HMD.[23] In many cases, the data are available from *International Historical Statistics* (Palgrave Macmillan (Ed.) 2013), which we abbreviate as *IHS* below. For infant mortality rates, we rely on official vital statistics except when demographic scholarship offers better estimates. In general, we calculate sex-ratio values (girls/boys in the under-five population) from official population counts by sex and age, most often census counts. For registry-based sex ratios, we take values at five-year intervals. Specific sources and methods by country follow.

Australia (1876–1971)

Infant mortality rates for 1876–1901 are from McDonald et al. (1987:58).[24] Rates for 1901–1971 are from Australian Bureau of Statistics, Historical Population.[25]

Under-5 populations by sex are census values for non-aboriginal populations. We have decennial data from 1881–1921 and 1961–1971, and single-year values for 1933, 1947, 1954, and 1966.
The data for 1881 and 1891 are reported in Caldwell (1987:33–34).
The 1901 and 1911 data are from the 1911 Census of Australia.[26]
Data for 1921, 1933, 1947, 1954, 1961, and 1966 are reported in the Census of 1966.[27]
The data for 1971 are calculated from values for the total and aboriginal populations in the 1971 census. Age by sex for the total population is in Part 9 of Bulletin 1, *Summary of Population*.[28] The age-sex data for the Aboriginal population are from Bulletin 9. *The Aboriginal Population*.

Austria (1865–1971)

Infant mortality rates (1865–1971) are from *IHS* (2013: 3577, 3580, 3583), Series A7.

[23] The HMD "is limited by design to populations where death registration and census data are virtually complete," but for our analysis we include populations with credible but incomplete infant mortality and sex-ratio data.

[24] Series MFM 154

[25] Deaths data downloads, Table 5.4 "Infant mortality rates, states and territories, 1901 onwards", released 2019-04-18; accessed 2021-06-21

[26] *Census of the Commonwealth of Australia taken for the night between the 2nd and 3rd April, 1911*, Vol. II, Part 1 – Ages, pp. 10-11.

[27] Commonwealth Bureau of Census and Statistics (1970), *Census of Population and Housing, 30 June 1966 Commonwealth of Australia.* Volume 1. Population: single characteristics, part 1. Age, pp. 10–11.

[28] *Census of Population and Housing, 30 June 1971, Commonwealth of Australia, Bulletin 1. Summary of Population*, Part 9 Australia, p. 1.

Under-5 populations by sex are for the years 1869 and 1934, and decenially 1880–1910 and 1951–1971.
The data for 1869 and 1910 are from *IHS* (2013: 3440), Series A2.[29] The data for 1880, 1890, and 1900 are reported in editions of *Österreichisches statistisches Handbuch*.[30]
The data for 1934, 1951, and 1961 are reported in Statistik Austria, *Statistisches Jahrbuch 2010*.[31]
For the years 1865–1910, Austria refers to Austria-Hungary (as in *IHS*); for later years Austria refers to the Republic of Austria (whose area in 1910 had less than 1/4 of the population of Austria-Hungary (*IHS* 2013: 3402, 3440)).

Belgium (1842–1970)

Infant mortality rates (1842–1970) are HMD data (downloaded on 2021-10-26).

Under-5 populations by sex are census data, decennially 1846–1866 and 1880–1910, with single-years 1930, 1947, 1961, and 1970. The data were obtained through the HMD (downloaded on 2021-07-01).
The data for 1846, 1856, 1866, 1880, 1890, 1900, and 1910 are reported in the volumes for 1893, 1908, and 1923–24 of *Annuaire Statistique de la Beligique*[32] HMD reports that the data for 1930 are in the 1940 volume of *Annuaire Statistique de la Beligique ed du Congo Belge* (pp. 34–35). HMD reports that the data for 1947 are published in volume 5 of the 1847 census of Belgium.[33]
HMD reports that the data for 1961 are published in volume 5 of the 1961 census.[34] HMD reports that the data for 1970 are published in volume 5 of the 1970 census.[35]

Denmark (1836–1970)
Infant mortality rates (1836–1970) are HMD data (downloaded on 2021-10-26).

Under-5 populations by sex are quinquennial 1840–1860 and 1910–1970, and decennial 1870–1890. The data were obtained through the HMD (downloaded on 2021-07-01), which identifies the source as Danmarks Statistik.

[29] Austrian provinces of the Hapsburg Empire. The values here are rounded to the nearest thousand; although we prefer unrounded data, we were unable to locate the data in official sources.

[30] For 1880: *1886* p. 3; for 1890: *1893*, p. 6; for 1900: *1909*, p. 7.

[31] 2.08 Bevölkerung 1869 bis 2001 nach fünfjährigen Altersgruppen und Geschlecht (Population 1869 to 2001 by five-year age groups and sex, p. 45

[32] For 1846, 1893:64; for 1856, 1909:64; and 1926:30 for 1866 and decenially 1880–1900. These are available online from HathiTrust (1893 and 1908 and 1923–24)

[33] Institut National de Statistique (1951), *Recensement Général de la Population, de L'Industrie et du Commerce au 31 décembre 1947, tome V, Répartition de la population par âge*, Tableau 1 - Répartition des habitants par âge et sexe . . . " (p. 10). Bruxelles: Imprimerie Fr. Van Muysewinkel.

[34] Institut National de Statistique (1965). *Recensement Général de la Population, 31 décembre 1961, tome V, Répartition de la population par âge.* Bruxelles (publisher and pages not given in HMD source notes).

[35] Institut National de Statistique (1974). *Recensement Général de la Population, 31 décembre 1970, tome V, Répartition de la population par âge.* "Population selon l'état civil et par âge". Bruxelles (publisher and pages not given in HMD source notes).

England and Wales (1847–1971)

Infant mortality rates (1847–1971) are from Mitchell & Deane (1962:36-37) for 1847-1937 and from *IHS* (2013: 3582, 3587) for 1942-19171.

Under-5 populations by sex for England and Wales are decennial for 1851–1891 and quinquennial for 1901–1971. The decennial data (1851–1891) are from the censuses of England and Wales, as reported in Mitchell & Deane (1962:12). The quinquennial data (1901–1971) are from the Historic Mortality Datasets of the National Archives.[36]

Finland (1881–1970)

Infant mortality rates (1881–1970) are HMD data (downloaded on 2021-10-26).

Under-5 populations by sex are quinquennial from 1885 to 1970, obtained through the HMD (downloaded on 2022-02-28) and the HMD identifies Statistics Finland as the source of the data.[37] **France (1897–1968)**

Infant mortality rates (1897–1968) are HMD data (downloaded on 2021-10-26).

Under-5 populations by sex are quinquennial 1901–1946, with single-years 1954, 1962, 1968. The data were obtained through the HMD (downloaded on 2021-07-01), which identifies the source as Vallin & Meslé (2001).[38]

Germany (1876–1933)

Infant Mortality Rates (1876–1933) are from IHS (2013: 3577, 3580), Series A7.

Under-5 populations by sex are census values, decennially for 1880-1910, with single-years

[36] RG 69/2, Historic Mortality: 1901–1995 dataset, Population, 1901–1995 (file POPLNS.csv), downloaded 2021-06-18.

[37] Under-five populations for 1885–1940 and 1945–1970 were received as computer files by the HMD from Statistics Finland: "Population estimates for years 1866–1940," and "Population estimates for years 1941–1995." This according to the "Data Sources" (https://mortality.org/hmd/FIN/DOCS/ref.pdf – login required) on the Finland page of the HMD website (accessed 2022-03-02.)

[38] The "Data sources" (https://mortality.org/hmd/FRATNP/DOCS/ref.pdf – login required) on the HMD data page for France describe the source as follows: "Vallin, J. and F. Meslé. (2001). Tableau I-C-1: Population par sexe et âge (de 0 à 100 ans), au 1 janvier, de 1899 à 1998, avec deux estimations selon le territoire pour les années de changement de territoire [revised post-publication]. In: Tables de mortalité françaises pour les XIXe et XXe siècles et projections pour le XXIe siècle. Paris: Institnational d'études démographiques.cite Table Tableau I-C-1: Population par sexe et âge (de 0 à 100 ans), au 1 janvier, de 1899 à 1998."

1925 and 1933. The data are from various years of the *Statistisches Jahrbuch.*[39] IHS (2013:3454, Series A2) also reports these age-sex population data, but rounded to the nearest thousand.[40]

West Germany (1960–1970)

Infant mortality rates (1956–1970) are HMD data (downloaded on 2021-10-26).

Under-5 populations by sex for 1960, 1965 and 1970 were obtained through the HMD (downloaded on 2021-10-26), which identifies the source as Statistisches Bundesamt.[41]

East Germany (1960–1970)

Infant mortality rates (1960–1970) are HMD data (downloaded on 2021-10-26).

Under-5 populations by sex for 1964 and 1970 are census data, obtained through the HMD (downloaded on 2021-10-26), which identifies the source as Statistisches Bundesamt[42]

Italy (1907–1971)

Infant mortality rates (1907–1971) are from Istat (Italian National Institute of Statistics) Time Series.[43]

Under-5 population by sex are decennial 1911–1931 and 1951–1971; also 1936; from Istat, Time Series.[44]

New Zealand (1863–1971)

Infant mortality rates are for the non-Maori population from 1863–1945 and for the total

[39] The 1880 data are from the 1883 *Statistisches Jahrbuch*, p. 10; 1890 data are from the *1896* volume, p. 5; 1900 from *1903*, p.6; 1910 from *1919,* pp. 6–7; 1925 from *1929*, p. 14; 1933: *1939*, p. 14.

[40] The IHS value for 1933 differs from ours; we use the value from the 1933 census (June 16); the IHS values for 1933 are consistent with the estimates for Dec. 31, 1933, found in *Statistisches Jahrbuch 1936*, p. 12.

[41] Annual population estimates as of December 31st, by age (0–94, 95+) and sex. Unpublished data.

[42] The "Data Sources" (https://mortality.org/hmd/DEUTE/DOCS/ref.pdf – login required) on the HMD data page for East Germany gives the source as "Statistisches Bundesamt, ed. (1996). Bevoelkerungsstatistische Uebersichten 1946 bis 1989 (Teil II). Wiesbaden: Arbeitsunterlage. (Sonderreihe mit Beitraegen für das Gebiet der ehemaligen DDR, Heft 28). The reference days were: 1964-12-31, 1971-01-01 and 1981-12-31."

[43] Health, Infant mortality rate by age at death and sex; perinatal mortality rate by sex - Years 1863-2013 (Table_4.8.xls).

[44] Population, Population by age class and sex, aging ratio and dependency ratio at Census from 1861 to 2011 according to reference year borders (Table_2.2.1.xls).

population from 1947–1970. Data for 1863–1936 are from Stats NZ Store House.[45] The data for 1936–1945 are from The New Zealand Official Year-book 1957.[46] Data for 1947–1971 are for the total population (including Maori), from Stats NZ Inforshare.[47]

Under-5 census populations by sex are for 1867, 1874, and 1881; quinquennially for 1886–1926 and 1951–1971; and also for 1936 and 1945. Data are for the non-Maori population until 1951. The data for 1867, 1874, and 1881 are found in the 1881 census.[48]

Quinquennial data for 1886–1916 are reported in the 1916 census.[49]

The data for 1936, 1945, and quinquennially 1951–1971, are from the Stats NZ Store House.[50]

Netherlands (1855–1970)

Infant mortality rates (1855–1970) are HMD data (downloaded on 2021-10-26).

Under-5 populations by sex (1859, 1869, and quinquennially 1875–1970) were obtained through the HMD (downloaded on 2021-07-01), which identifies the sources as the NIDI mortality database for 1859–1949 and Statistics Netherlands (Centraal Bureau voor de Statistiek) for 1950–1970.

Norway (1886–1970)

Credible IMR data for Norway start with 1876. Although counts of births and infant deaths start with the year 1836, we are guided by the judgment of Julie E. Backer, writing as "former chief of the Population Statistics Division, Central Bureau of Statistics of Norway". According to Backer (1961, p. 36), until 1876 infants who died early inflated counts of the stillborn, with live-births and infant deaths correspondingly understated.[51] Although some early publications from Statistics Norway report IMR data from before 1876, their

[45] A2.7 Infant mortality rate and infant mortality number (spreadsheet), Thorns/Sedgwick non-Maori (column 3).

[46] Section 4 – Vital Statistics. European Infant Mortality.

[47] Population, Death Rates - DMM, Infant mortality rate (Annual-Dec).

[48] *Results of a census of the colony of New Zealand, taken for the night of the 3rd of April, 1881*, Chapter 28, Table 1, "Showing the Increase of Persons of Both Sexes, Males, and Females (exclusive of Maoris), at different Ages, in the Intervals between the various Censuses, from December, 1864, to April, 1881."

[49] *Results of a census of the Dominion of New Zealand . . . 1916*, Part II Ages, p. 1.

[50] Spreadsheet (182.xls) titled A1.6 Population by age and sex (Long-term data series; Population;), spreadsheet A1.6 (citing Bloomfied (1984), "Census Reports: Table II.6. Age Groups . . . 1874-1976").

[51] STATISTISK SENTRALBYRÅ (Oslo 1961): Dette førte til at tallet på registrerte levende fødte og døde barn ble for lavt og tallet på dødfødte for høyt. De gjeldende bestemmelser om hva en skulle forstå med et levende og dødfødt barn ble imidlertid stadig innskjerpet overfor jordmødrene, og fra 1876 kan en gå ut fra at de tall som står oppført i den offisielle statistikk stort sett gir et riktig uttrykk for forholdet. See also "Preface" (unpaged) regarding Backer's authorship.

Historical Statistics of 1978, 1994, and 2000 present 5-year average values of IMR starting with 1876. In our view, that corroborates our conclusion that 1876 marks the start of reliable IMR data for Norway.

Infant mortality rates (1886–1970) are from IHS (2013: 3578, 3581, 3585); Statistics Norway online data on births and infant-deaths corroborate the IHS infant mortality data.[52]
Under-five populations by sex are census values, decennially 1890–1930 and 1950–70; and 1946.[53] Data for 1890–1900 are from Statistics Norway (1910).[54] Data for 1910–1930 are reported in the 1930 census.[55] The rest of the age-sex data for Norway are taken from published census volumes from the respective years: 1946 from Statistics Norway (1951), *Folketellingen 1946, Hefte 3*[56]; 1950 from Statistics Norway (1953), *Folketellingen 1950, Hefte 2.*[57]; 1960 from Statistics Norway (1963), *Folketellingen 1960, Hefte 2.*[58]; and 1970 from Statistics Norway (1971)[59](https://www.ssb.no/a/histstat/nos/nos_a448.pdf) (Population by age and marital status 31 December 1970), pp. 24–25.].

Scotland (1857–1971)

Infant mortality rates (1857–1971) are HMD data (downloaded on 2021-10-26).

Under-5 populations by sex are decennial 1861–1901 and quinquennial from 1911 to 1971; the data were obtained through the HMD (downloaded on 2021-07-01); original sources are as follows. The quinquennial data for 1861 to 1881 are published in the 1881 census.[60] Data for 1891–1901 are in the 1901 census.[61]

Quinquennial data for 1911 to 1936 are from the General Register Office for Scotland.[62]

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[52]Statistisk sentralbyrå, Historisk statistikk, 3.13 Folkemengde, fødte, døde, ekteskap, flyttinger og folketilvekst.

[53]The census values refer to January 1 of a year so we treat them as the prior year's ending value (so our 1890 U5 counts are from the January 1, 1891 census). The IHS and HMD list Norway's population data with the census years (so our 1890 value is listed in HMD as 1891).

[54]*Norges Folkemængde fordelt paa de enkelte aldersaar, 1846-1901*, Norges Officielle Statistik. V. 113, pp. 32, 34.

[55]Statistics Norway (1934), Folketellingen 1930, Hefte 5. *Folkemengden fordelt efter kjønn, alder og ekteskapelig stilling*, p. 2.

[56]*Folkemengden etter kjønn, alder og ekteskapelig stilling, . . .*, Tabeller p. 2.

[57]*Folkemengden etter kjønn, alder og ekteskapelig stilling . . .* (Population census December 1, 1950, Second volume, Population by sex, age, and marital status . . .), Tabeller p. 2.

[58]*Folkemengden etter kjønn, alder og ekteskapelig status.*

[59]*Folkemengden etter alder og ekteskapelig status 31. desember 1970*

[60]Scotland Census Office (1883), *Ninth decennial census of the population of Scotland . . . 1881 . . . Vol. II*, Appendix tables; with the 1861 and 1871 data in Table XXII, "Population of Scotland in 1861 and 1871, in sexes and ages . . . " (p. xxxii) and the 1871 and 1881 in Table XXI, "Population of Scotland in 1871 and 1881, in sexes and ages . . . " (p. xxxii). The volume is available online from HathiTrust.

[61]Scotland Census Office (1903), *Eleventh decennial census of the population of Scotland . . . 1901 . . . Vol II*, Appendix Tables, Table 1, "Population of Scotland in 1891 and 1901, distinguishing males and females at each year of life . . . " (p. xxxii). Available online from Google Books.

[62]Mid-year population estimates by sex and five year age group, 1911-1938. The HMD reports these as

Quinquennial data for 1941 to 1971 are from General Register Office for Scotland.[63]

South Africa (1913–1921)

Infant mortality rates (1913–1921) are from *IHS* (2013:219) Series A7.

We have under-5 census populations by sex for 1918 and 1921, reported in the 1922 and 1925 volumes of the *Official Yearbook* of South Africa.[64]

Sweden (1856–1970)

Infant mortality rates (1856–1970) are from Statistics Sweden.[65]

Under-five populations by sex are quinquennial from 1860 to 1970, with the data online from Statistics Sweden.[66]

Switzerland (1875–1970)

Infant mortality rates (1875–1970) are calculated from data on births and infant-deaths from Historical Statistics of Switzerland, Marriage, Birth, and Death.[67] These IMRs are corroborated by *IHS* (2013: 3578,3582) Series A7.

We have under-5 populations by sex for 1880, 1888, decennially 1900–1930, 1941, and decennially 1950-1970. The data are from Historical Statistics of Switzerland, Population[68]

"Retrieved 15 May 2008" http://www.gro-scotland.gov.uk.

[63]Mid-year population estimates by sex and single year of age until the last age 85+ (1939-1970) or 90+ (1971-2001); unpublished data received by HMD via email on 28 February 28, 2007.

[64]The 1918 data are in Union office of census and statistics (1923), *Official Yearbook of the Union and of Basutoland, Bechuanaland Protectorate and Swaziland, No. 5 –1922* (pp. 158–59); Pretoria: The Government Printing and Stationary Office. The 1921 data are in Union office of census and statistics (1927), *Official Yearbook of the Union and of Basutoland, Bechuanaland Protectorate and Swaziland, No. 8 –1925* (p. 868); Pretoria: The Government Printing and Stationary Office.

[65]Live births, stillbirths and infant mortality rates by sex. Year 1749–2020.

[66]Statistical Database, Population, Population statistics, Number of inhabitants, Population by age and sex. Year 1860–2021 (accessed 2022-02-28).

[67]HSSO, 2012. Tab.C.41. hsso.ch/2012/c/41 (Total Deaths (Excluding Stillborn Births) by Age Group 1867–1995) and HSSO, 2012. Tab.C.5a hsso.ch/2012/c/5a (Marriage, Birth, and Death 1867–1995: General Overview).

[68]HSSO, 2012. Tab. B.8a. hsso.ch/2012/b/8a (Total Residential Population by Age in Five Year Increments (Approximate Ages), 1860–1990)

United States (1915–1970)

The 1920 and 1930 data are for the states of the Birth Registration Area (BRA) of those years. The US census data for these years refers to populations as of April 15; for an appropriate average IMR to associate with the April 15 U5 populations, we take an average across the 6 years up to the census year, with year t-6 weighted ¾ of one-fifth, year t weighted ¼ of one-fifth, and the other 4 years each weighted one-fifth (thus we treat April 15 as one-quarter through the year). The states included for 1915-1920 were DC ME MA MI MN NH NY PA VT (RI was also in the BRA at this time, but IMR data were missing for 1919 & 1920. The states included for 1925-1930 were the 1915-1920 set plus CA IL IN IA KS MI MT NE NJ ND OH UT WA WI WY DE FL KT MD NC VA WV and RI. In addition to the data sources (below), see U.S. Department of Health, Education, and Welfare (1954) on the "History and organization of the vital statistics system" in the US.
Infant mortality data for 1915–1920 and 1925–1930 are from Linder & Grove (1947).[69] We use birth counts to aggregate state-level rates; the births data are from the annually published *Mortality Statistics* (available online from the National Center for Health Statistics).
Infant mortality rates for the US as a whole (1936–1970) are from U.S. Department of Health, Education, and Welfare (1996). *Vital Statistics of the United States 1992, Volume II – Mortality.*[70]

Under-5 populations by sex are census data. For 1920 and 1930, the data by state are published in the 1930 censusˆ[US Department of Commerce, Bureau of the Census, *Fifteenth Census of the United States: 1930. Volume 2.* Population, General Report, Statistics by Subjects, Table 24. Age by 5-year periods, by color, nativity, and sex, by divisions and states: 1930 and 1920 (pp. 611–659),

Decennial data for the US from 1940 to 1970 are reported in the 1980 Census.[71]

Massachusetts (1861–1915)

Infant mortality rates (1861–1915) are from *Historical Statistics of the United States* (US Bureau of the Census, 1975:57).[72]

Under-five populations by sex, quinquenially 1865 to 1915, are census data. These are decennial data for 1865–1915 from published volumes of the State of Massachusetts census and decennial data for 1970–1910 from the published volumes of the US Census.

[69] *Vital Statistics Rates in the United States 1900-1940,* by F. E. Linder & R. D. Grove (National Office of Vital Statistics, 1947), Table 28, pp. 585-605 (available online from the NBER).

[70] Section 2. Infant Mortality, Table 2-2 "Infant, neonatal, and postneonatal mortality rates, by race: Birth-registration States, 1915–32, and United States, 1933-92" (pp. 3–4 of Section 2; pdf pp. 507-08).

[71] *1980 Census of Population, General Population Characteristics, United States Summary, Table 45. Age by Race and Sex: 1910 to 1980 (p. 1–42).

[72] Chapter B. Vital statistics and health and medical care, Series B148. Infant mortality rate for Massachusetts: 1851–1970. Available online from the US Census Bureau.

The sources of the age-sex data from the Massachussets state census are as follows:
Abstract of the Census of Massachusetts, 1865.[73]
The census of Massachusetts: 1875. Volume I. Population and social statistics.[74]
The census of Massachusetts: 1885. Volume I. Population and social statistics, Part 1.[75]
Census of the Commonwealth of Massachusetts: 1895. Volume II. Population and social statistics.[76]
Census of the Commonwealth of Massachusetts 1905, volume 1, population and social statistics.[77]
The decennial census 1915.[78]

The sources of the age-sex data for Massachusetts from the US census are as follows:
Ninth census – volume II. The vital statistics of the United States (June 1, 1870).[79]
Statistics of the population of the United States at the tenth census (June 1, 1880).[80]
Report on the population of the United States at the eleventh census: 1890, Part II.[81]
Twelfth census of the United States, taken in the year 1900, Population Part II (Census Reports Volume II).[82]
1910 Census, Volume 1. Population, general report and analysis.[83]

[73] Table 1. "Census of Massachusetts, 1865, Distinguishing by Age and Sex, the Number of Inhabitants", p. 2

[74] Ages, p. 269, corrected: the published total for age-one females is 15589 which is an error; the sum of the county values (pp. 263-68) of age-one females is 13589 (the published male total is correct, 13825).

[75] "Ages: under 1 to 80 years and over", p. 434.

[76] "Ages: by five-year periods (by sex)", p. 422

[77] "Ages: under 1 to 80 years and over", p. 480.

[78] Table 25. Ages by native and foreign born and sex, and native and foreign born by color or race, and sex, for the state", p. 478.

[79] The tables of ages. Table XXIII. "Ages with sex for each period of life, of the aggregate population of the United States, by states and territories, 1870–1850", p. 563.

[80] Table XXI. "Population, by Specified Age, Sex, Race, and General Nativity of the Whites, by States and Territories: 1880", p. 592.

[81] Table 3. "Ages by periods of years of the aggregate population, classified by sex, by states and territories: 1890", pp. 104–105.

[82] Ages, Table 3. "Ages by periods of years of the aggregate population, classified by sex, by states and territories: 1900", pp. 110–111.

[83] *Thirteenth census of the United States taken in the year 1910, volume 1, population 1910, General Report and Analysis*, Table 43 "Distribution by age periods of the population, and by each year of age for persons under 25, by divisions and states: 1910", p. 380.

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U.S. Department of Health, Education, and Welfare (1996). *Vital Statistics of the United States 1992, Volume II – Mortality*.