Infant Sex Ratios and Infant Mortality in North America: 1850-1920

Jesse McDevitt-Irwin and James R. Irwin*

15 June, 2021

Abstract

Male-biased sex ratios are familiar as indicators of mortal misogyny and missing women. However, due to the female mortality advantage in infancy, infant sex ratios are also informative of infant mortality and maternal health, a point under-appreciated to date. In this paper, we use infant-sex-ratio evidence to uncover basic patterns of infant mortality in North America from the 1850s to the 1920s, the eight decades before national vital statistics provide infant mortality data. Unlike well-documented European cases, the basic facts of infant mortality in North America before the 1920's remain to be established. At stake are key questions on health and well-being during 19th-century 'modernization' (e.g. Engels 1845, Komlos 1998). Infant sex ratios from the US and Canadian censuses suggests two major revisions to current characterizations of North American infant mortality. First, infant mortality in mid-19th century North America was distinctly lower than in Europe, likely reflecting lower levels of urbanization. Second, infant mortality worsened in eastern North America in the last quarter of the 19th century, approaching levels typical of Europe. On our evidence, modernization's toll on the health of infants and mothers was somewhat delayed and attenuated in North America compared to Europe.

A manuscript prepared for the 2021 meetings of the Canadian Economic Association. Comments and suggestions welcome.

*Authors' information: Corresponding author is Jesse McDevitt-Irwin, PhD Student in Sustainable Development at Columbia University (jrm2275@columbia.edu). James R. Irwin is Professor Emeritus (Economics), Central Michigan University. We thank Douglas Almond, John Komlos, Robert Margo, Samuel H. Preston, Rodrigo Soares and Jeffrey Shrader for encouraging comments on the initial stage of this project. We also thank Hoyt Bleakley, Lou Cain and Kris Inwood for comments on our later drafts. Jesse McDevitt-Irwin thanks his lab partners Claire Palandri and Vincent Bagilet for their continued comments.

1 Introduction

Across the 20th century in Europe, infant mortality plummeted. Circa 1900, infant mortality rates in Europe were on the order of 100 to 300 deaths per 1000 infants; by the 1990s, rates were under 10. The well-documented collapse in European infant mortality has been called "one of the most extraordinary victories that humanity has known" (Masuy-Strooban 1997:26). Presumably something similar occurred in North America, but by the time national vital statistics became available to document infant mortality (1921 in Canada, 1933 in the US), infant mortality was already low by the standards of late-19th century Europe.[1]

It remains to be seen whether the US and Canada followed the European path of infant mortality transition. Of particular interest to economic historians, substantial declines in infant mortality came quite late in Europe's "industrial revolution" (Cipolla 1978:27-44; Clark 2007). Viewing infant mortality as a key indicator of well-being in a population, lags between the onsets of income growth and mortality decline contribute to pessimistic perspectives on the standard of living during the industrial revolution.[2]

Moreover, high rates of infant mortality in the modernizing economies of 19th-century Europe serve to remind that "all good things do not necessarily go together" (Engerman 2003:185). With industrial revolution well underway across North America by the later 19th century, identifying historical patterns of infant mortality in the US and Canada holds great promise for revealing the extent to which 19th-century economic growth came at the cost of infant and maternal health.[3] We see two key lines of argument to keep in mind: first, urbanization is expected to increase infant mortality, because cities were unhealthy places well into the 20th century (Haines 2001); second, income growth is expected to decrease infant mortality, via improvements in nutrition (McKeown 1976). To the extent that urbanization was inexorably bound up with 19th-century economic growth, infant mortality was being pulled in opposing directions.

Our contribution is to draw on a novel indicator for infant mortality and maternal health: infant sex ratios. Sex ratios are familiar from social science research pursuing Sen's (1990, 1992) call for attention to "missing women." The millions of missing women across the world has justifiably focused scholarly attention on male-biased sex ratios and the sex discrimination which they imply. However, because of the female mortality advantage, infant sex ratios can also be an informative indicator of poor maternal-infant health.[4] Moreover, infant sex ratios are readily available from

[1] About 60 deaths per 1000 infants in the US in 1933 (HSUS Ab920); about 100 in Canada in 1921 (Wadhera and Strachan 1993:22 (CS82-549)).

[2] For example, from economic history, see Engerman's (1997) review of the "standard of living debate," or Komlos (1998) on the "antebellum puzzle" in the US. For an account from social history, see the work of Griffin (2018).

[3] Note that infant and child mortality have occupied a key position in the debates over 19th-century standards of living from the start, with Engels commenting that "the great mortality among children of the working class . . . is proof enough of the unwholesome conditions under which they pass their first years" (Engels, 1845: 150).

[4] Researchers exploring "missing women" have also recognized that excess male infant and child mortality generates a relationship between mortality and infant sex-ratios. Most recently, Beltrán Tapia & Raftakis (2021) consider a plot of the under-5 sex ratio against the infant mortality rate, identifying male-biased outliers as suspected cases of

census data, making them particular useful for research on historical populations which lack vital statistics.

The paper is organized as follows. We close this introductory section by presenting the current facts of infant mortality in North America, establishing the empirical gap we seek to fill. Section 2 starts with the theory and evidence underpinning our use of infant sex ratios as indicators of infant and maternal health. We follow with simple and relevant applications of our methods, showing the close relationship between infant sex ratios and infant mortality where we have both data (the period 1850-1990 for England and Massachusetts). Section 3 tackles the question of infant mortality in the US as a whole for the period before we have data on infant mortality from national vital statistics. Although our sex-ratio-evidence is a blunt tool for unpacking infant mortality trends, it offers a powerful challenge to widely-cited estimates of US infant mortality in the 19th century. Section 4 narrows the geographic focus to the eastern US and Canada, and takes a dis-aggregated approach, breaking out four key census-divisions of the 19th-century US. Looking across US regions and Canada reinforces our findings for the US as a whole, and points more strongly to the conclusion that income gains did not produce mortality gains.

1.1 The Collapse of Infant Mortality

The record of infant mortality in Western Europe since the mid-19th century is well-documented.[5] With an eye toward uncovering patterns in North America, the key feature of the European record is the veritable collapse of infant mortality across the 20th century. Infant mortality rates in the range of 100 to 300 deaths per thousand prevailed across Europe during the second half of the 19th century, but fell to less than 10 per thousand by the 1990s. Two points bear emphasis here: first, the 20th-century collapse of European infant mortality occurred long after the onset of sustained economic growth for most of the continent;[6] and second, the collapse was consistent across a wide range of per capita incomes and initial levels of infant mortality.[7]

In contrast to Europe, basic facts of infant mortality in North America before World War I remain to be established.[8] The key obstacle to documenting North American infant mortality is a lack of

"missing girls."

[5]See Corsini and Viazzo (eds.) 1997, *The decline of infant and child mortality: the European experience, 1750-1990*, for an overview.

[6]Sweden is a notable exception, with infant mortality declining steadily across the 19th century, well before the onset of modern economic growth (Brändström, 1993). See Broadberry and O'Rourke (2010: 2) for a useful summary view of economic growth across Europe before 1870; for a more in-depth treatment, refer to the Maddison Project Database.

[7]It might be tempting to look for patterns connecting levels or growths of incomes to mortality change (or stasis) across the diversity of 19th-century Europe. However, that is well outside our scope, as suggested by van de Walle's (1986:215) summary statement: "Before the general massive drop in this century [the 20th], there were wide differences in levels and trends of infant mortality among European regions, among countries, and within each country."

[8]The past three decades have seen advances in our knowledge of mortality at older ages, but with reference to infant mortality, it remains true that "little is known about trends, levels, and differentials in American mortality in the 19th century. It is not altogether clear when or even whether mortality declined in the United States during the

vital statistics data. In both the US and Canada, national vital statistics developed slowly. It was not until 1924 that the US birth registry covered even three-quarters of the country's population; complete coverage dates from 1933. Similarly, in Canada national vital registration had to wait until 1921. In the 19th century, reliable vital statistics were very rare in North America, the state of Massachusetts offering a small but important exception.

We present the historical record of infant mortality (from vital statistics) for the US and Canada in Figure 1. The infant mortality rate (IMR) series runs from 1924 to 1990 for the US, and from 1921 to 1990 for Canada.[9] In Figure 1, we also plot infant mortality rates in the mid-19th century for a variety of European polities, with the gray shaded area representing the range of infant mortality rates found across Europe. We also give the infant mortality for the state of Massachusetts, the only sizable North American place with reliable infant mortality data as early as 1860 (Haines 2006: 385).[10] Although the state was not typical, Massachusetts was at least one piece of the infant mortality picture we hope to discern.[11] Taken together, the plots in Figure 1 present our current knowledge of the national infant mortality rates for the US and Canada, along with a set of relevant comparative cases. Put simply, our challenge is to locate the North American infant mortality experiences within the axes of Figure 1.

While it is clear in Figure 1 that the 20th century saw a substantial reduction in US and Canadian infant mortality, the magnitude and timing of North American mortality improvements remain to be determined. By the 1920s, when vital statistics data become available, North American infant mortality rates were already low by the standards of 19th-century Europe. In the US, the IMR series starts in 1924 with a value of just 60 deaths per thousand infants, a level far below the range of experience in 19th-century Europe.[12] The series for Canada starts in 1921 with a value of 102, substantially above the US starting point, but at the bottom of the range found in later 19th-century Europe.[13]

The most striking feature of Figure 1 is the expanse that lies to the left of the US and Canadian IMR series, reflecting the range of possible paths of infant mortality. Perhaps the US case fell within the European range; but if so, did the US escape from German-like levels of nearly 300? Or from Norway-like levels of around 100? We might expect that the US infant mortality experience

period" (Preston and Haines, 1991:49).

[9] Although national-level vital statistics for the US date from 1933, by 1924 the data cover over 3/4 of the US population, and are reasonably viewed as nationally representative. As discussed below, scholars of historical demography have made a variety estimates of US and Canadian infant mortality for before the vital statistics period. On our reading, such estimates are tentative in comparison to rates derived from vital statistics (registrations of births and deaths).

[10] See Mitchell (2013:32-36) for "Boundary Changes" to interpret the polity names in Figure 1.

[11] Massachusetts vital statistics data from 1851, but we present the average of 1860-1865, relying on Haine's (2006:1-385) judgment that the state's IMR series is reliable from 1860 onward.

[12] For example, van de Walle's (1986:212) Table 4.2 presents ranges of infant mortality rates across provinces in 11 European countries: in circa 1870, circa 1900, and circa 1930. The Table has no cases of infant mortality as low as 60 per thousand until circa 1930.

[13] In van de Walle's Table 4.2 (see prior footnote), before 1930, national infant mortality rates as low as 102 were seen only in 1900, in Sweden and in Norway. However, provinces with rates as low as 100 circa 1900 could be found in all of the countries listed in the table, except for Russia (in 1900; the lowest rate there being 147).

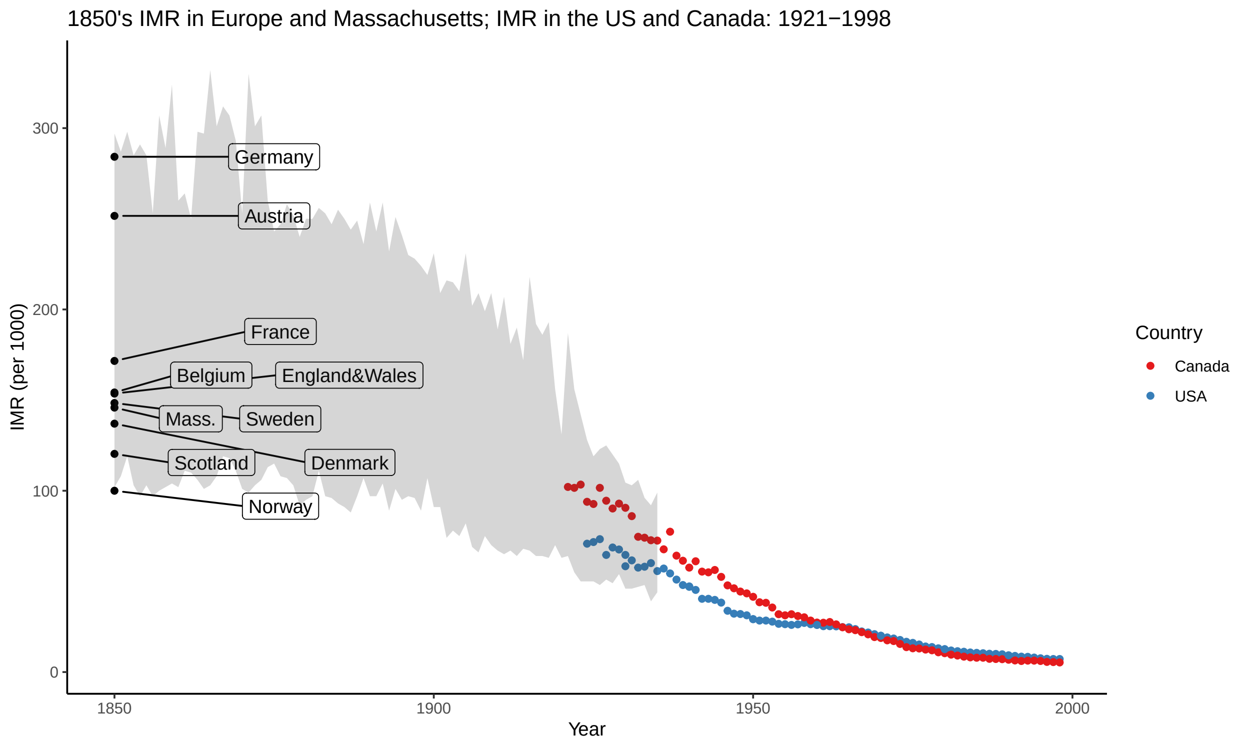

Figure 1: North American and European infant mortality rate (IMR). The gray ribbon represents the range of IMR across selected European polities. The US series begins in 1924, when the birth registration area reached 75% population coverage, while that of Canada starts in 1921. US data from the HSUS (2006); Canadian data from Statistics Canada; European data from International Historical Statistics (1998).

was more benign than Europe's, with superior maternal-infant health among the many magnets drawing immigrants across the Atlantic.

The authoritative work of Preston and Haines (1991) has shown that US child mortality began declining in the late 19th century. However, infant mortality need not follow the same pattern as child mortality. Moreover, infant mortality is particularly difficult to measure due to a lack of data, as noted in Haines (1979:290). Haines (1998) provides the currently-used estimates of infant mortality for the US before 1915, and finds that infant mortality declined substantially from 1850 to 1900. Without direct data on infant mortality, these estimates are derived from life-table analysis, with the raw data being older child and teenage mortality. Our contribution is to use census counts of infants by sex to provide new evidence on infant mortality.

Our broader goal is to begin to understand the health-consequences of economic growth in North America, and to contribute to the perennial debates over the pros and cons of urbanization, industrialization, and modernization more broadly. But for the present, we take up the challenge of identifying the most basic patterns of historical change in infant mortality in North America from the 1850s to the 1920s. To meet that challenge, we propose a novel indicator of maternal-infant health, infant sex ratios, drawing from demography and biology, as well as broader social- and natural-science scholarship.

2 Infant Mortality and Infant Sex Ratios

2.1 Demography and Biology of Infant Sex Ratios

Infant sex ratios are familiar as indicators of "missing women," but they are also closely tied to infant mortality.[14] Because female infants have a biological mortality advantage, a high rates of infant mortality will skew the infant sex ratio toward females – absent mortal misogyny (i.e. female infanticide or other extremes of gender discrimination). Scholars have long known that boys are both born and buried more often than girls.[15] The female mortality advantage is particularly strong in the first year of life, with male infant mortality typically 15-30% greater than female (Drevenstedt et al. 2008; Alkema et al. 2014).[16]

[14] Among many possible, see e.g. Sen (1990), Klasen (1994), Klasen & Wink (2002) for research on "missing women".

[15] This knowledge was nicely summarized in the report on the 1861 census of Scotland: "At birth 106 males appear for every 100 females ... yet, by the law of nature, a law seen in still more powerful operation even in intra uterine life, the tendency to succumb under disease is so much greater in the male than in the female, that by about the 18th year of life the proportion of the sexes becomes equalized, 100 males being alive at that age for every 100 females." These points have been noted since at least John Graunt (1662), followed by Arbuthnot (1710), and Clarke (1786) (cited in Bakwin, 1929). See Grech (2020) for "historical aspects" of the sex-ratio at birth (and excess male mortality, to a lesser extent).

[16] The female mortality 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).

The lower mortality of infant girls has powerful demographic implications for infant sex ratios. If a population has very low infant mortality, say 5 per 1000 like Canada in 2018, the relative numbers of boys and girls will be nearly the same during childhood as it was at birth. 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 infancy will be distinctly more female than it was at birth, male infants having been culled from the population at a greater rate than females.

We model the infant sex ratio using life-table concepts. The the ratio of girls to boys under age x can be modeled as the product of two factors: the relative number of boys and girls born, and the relative rate at which boys and girls survive to be observed. The rate of survival under age x is given by ${}_xL_0$, measured as a percentage of infants born of a given sex.[17]

Because infant mortality takes a lighter toll on girls than boys, the sex ratio among survivors will be female-skewed: ${}_xL_0^f >_x L_0^m$. The female skew of that sex ratio increases with the level of infant mortality – the greater is infant mortality, the more that the female mortality advantage is reflected in the survivors' sex ratio. This effect is central to our analysis, and it is evident in standard model life tables.[18]

In the panels of Figure 2, we model these relationships across the 20th-century US, drawing on Bell & Miller's (2005: 26-58) historical life tables for census benchmark years. In Panel A, Bell & Miller's infant mortality rates plummet across the century. Infant mortality is consistently greater for boys than girls, as expected, but their difference shrinks as both approach zero. In Panel B, we plot model infant survival rates (${}_2L_0$) by sex. The female survival rate (${}_2L_0^f$) is always greater than the male (${}_2L_0^m$), reflecting the female mortality advantage, but they both approach one as infant mortality approaches zero. Note that both would equal 100 if mortality were zero. In Panel C, we plot the ratio of these two survival rates: $\frac{{}_2L_0^f}{{}_2L_0^m}$. As infant mortality falls towards zero, the female-skew in the survivors' sex ratio falls, and the ratio approaches one. Looking ahead to observable data, as the survivors' sex ratio falls toward one (no female-skew), the under-2 sex ratio approaches the ratio of girls to boys born (i.e. the empirical effect of the female mortality advantages becomes negligible at low rates of infant mortality).

To summarize, infant sex ratios are closely related to infant mortality because of the female mortality advantage. As seen in Figure 2, as infant mortality declines, the sex ratio of survival approaches one, driving the infant sex ratio towards the sex ratio at birth.

Conceptually, the infant sex ratio is the product of the sex ratio at birth and the sex ratio of infant survival rates ($\frac{{}_xL_0^f}{{}_xL_0^m}$). The latter term is our focus, because it is directly connected to infant

[17]Note that we are modelling the population in an age interval, so we use the life table capital L_x (person-years lived in the interval), rather than lower-case l_x (the number surviving to exact age x). ${}_xL_0$ represents, roughly, the expected number of individuals in an age grouping of 0 to x. It is equal to the rate who survive to age x plus the average time lived of those who die: ${}_xL_0 = 1 -_x q_0 +_x a_0 *_x q_0$. ${}_xq_0$ is the mortality rate between age 0 and x, while ${}_xa_0$ is the "separation factor".

[18]E.g. in the model West life tables: moving from level 11 to level 16, the IMR falls from 160 to 91 (per thousand), and the $Lx2 = \frac{{}_2L_0^f}{{}_2L_0^m}$ from 102.2 to 101.0.

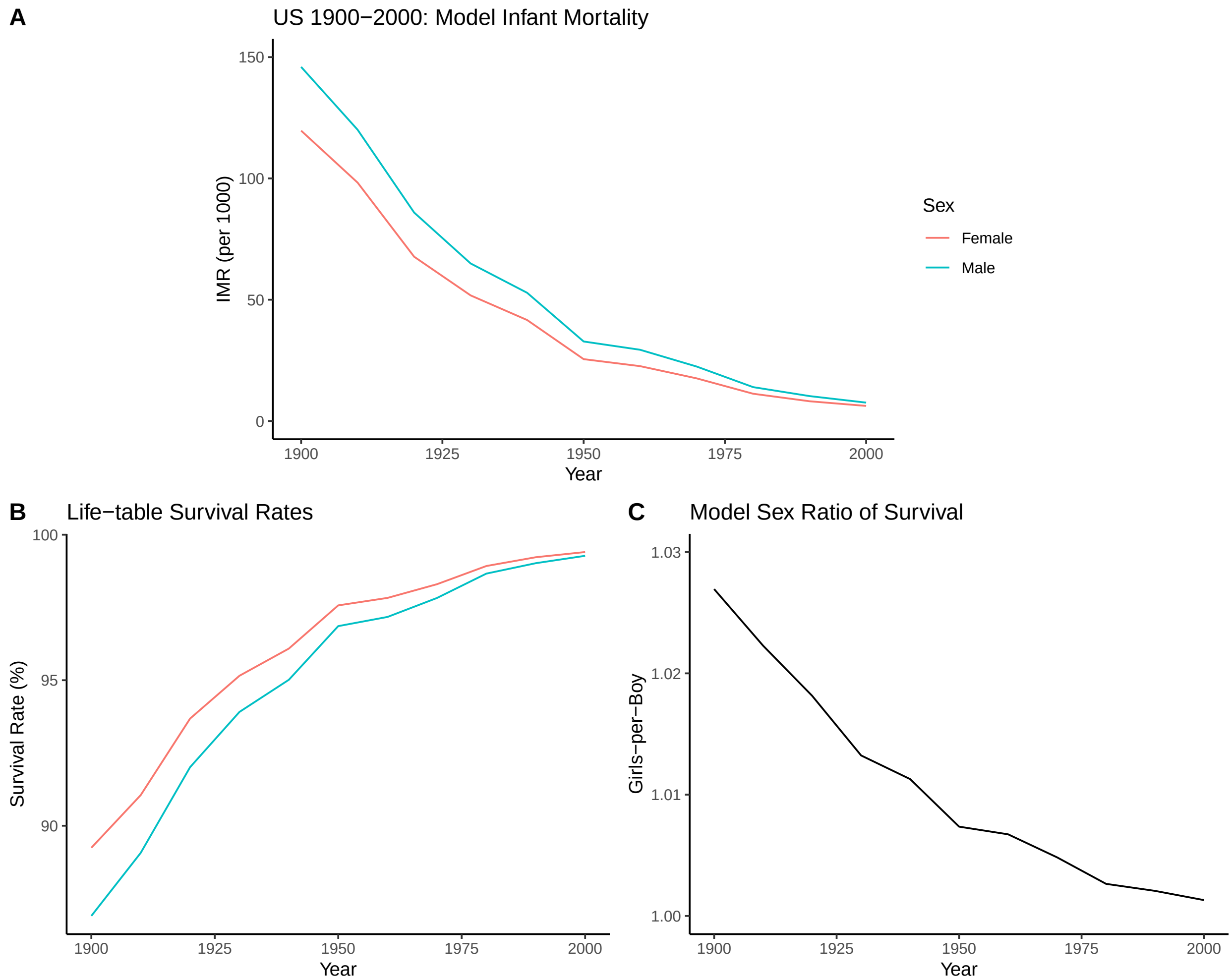

Figure 2: Panel A: US infant mortality rate, 1900-2000. Panel B: life-table survival rates ($_2L_0$) by sex. Panel C: life-table sex ratio of survival, $\frac{_2L_0^f}{_2L_0^m}$. Source, US CDC actuarial life tables, from Bell and Miller (2005).

mortality, as shown above. However, the sex ratio at birth requires some attention as well, especially in view of research that connects maternal health to sex-biased birth outcomes. Put simply, poor maternal health tends to tilt the sex-ratio at birth toward females.[19] In healthy populations, the sex ratio had birth is slightly skewed away from females, with about 95% as many girls as boys born alive. However, a growing body of research demonstrates that maternal stress, pollution and poor socio-economic conditions all lead to relatively more female births.[20] Therefore, female-biased sex ratios are signals not only of infant mortality but also maternal health. Given our focus on infant mortality in this paper, we tend to abstract from the potential role of changes in the sex ratio at birth, but it is worth stating our maintained assumption that the health of infants and their mothers were closely tied together in the populations we study.[21]

2.2 Infant Sex Ratios in the 20th-century US

The theory outlined above predicts a close relationship between infant mortality and infant sex ratios. Next we put this logic to a simple test. The 20th century saw substantial decline in infant mortality in the US, which should be reflected in infant sex ratios trending toward boys.

We test this implication using infant sex ratios as observed in the US census.[22] Figure 3 plots the ratio of girls to boys ages 0 and 1 (under-2) and ages 0 to 4 (under-5) for the 20th-century US. As a reference, Figure 3 includes a line representing a healthy sex ratio at birth, of 94.5 girls per 100 boys (or 105.8 boys per 100 girls).[23] That line is an asymptote, illustrating the infant sex ratio value when the infant mortality rate is zero. The higher the ratio of girls to boys, compared to that healthy sex ratio at birth, the greater the implied infant mortality. We also plot a model sex ratio, the blue dashed line, based on Bell and Miller's (2005) life tables for the US. In short, this line is the same as that of Panel C in 2 multiplied by a constant sex ratio at birth.

As seen in Figure 3, the observed data behaves just as predicted by demographic theory. The drastic improvements in infant mortality in the US since 1900 have been accompanied by substantial changes in infant sex ratios. As the IMR fell, so did the ratio of girls to boys, as fewer males were culled from the population. We interpret the 2-point decrease in the ratio of girls to boys across the twentieth century as reflecting improvements in maternal and infant health.[24] The relatively

[19]The apparent mechanism is maternal stress hormones, which increase the probability of miscarriages, which are disproportionately male (James and Grech 2017: 51).

[20]Important contributions include Catalano et. al. (2003, 2005, 2006, 2009, 2013) and Almond and Edlund (2007); and see references there.

[21]Separate attention to birth sex ratios and survival sex ratios may prove a fruitful avenue for future research. But for now we are satisfied that our sex-ratio evidence is informative on infant mortality narrowly, as well as maternal and infant health more generally.

[22]The data are from published census volumes (1850-1990) and from the full-count IPUMS-USA datasets (1850-1880, 1900-1940). When both sources are available, we average the two counts. As discussed below, the 1890 census values are suspect, so we isolate them in the figure.

[23]We use the sex ratio at birth in late-19th century Scotland to represent a healthy example (Maconochie and Roman 1997). Note that research on sex ratios at birth tends to explores variations that very small for purposes (values in the range of 94 to 95 girls per hundred boys are "healthy" here).

[24]A rather less uplifting and more dramatic view of sex ratio variation comes with attention to racial differences.

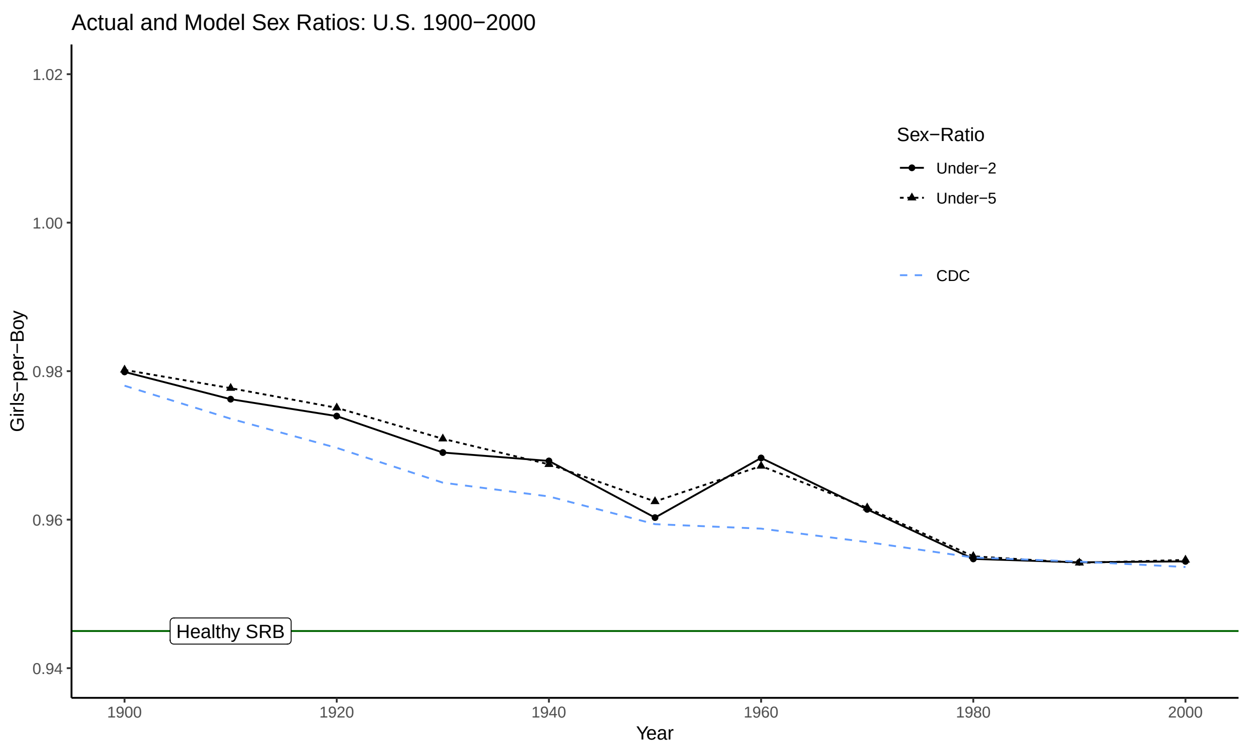

Figure 3: Ratio of girls to boys ages 0 and 1: US 1900-2000. Data from the US Census. The dashed line represents the model sex ratio (U-2) from CDC actuarial life tables (Bell and Miller, 2005). The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls).

female-skewed value for 1960 calls for further research, but for now it simply reminds that there may be unexplained or random variation in observed sex ratios.[25]

2.3 Evidence from Vital Statistics

Expanding our geographic and temporal scope, we find striking affirmations of the predicted relationship between infant mortality and infant sex ratios. Below we examine the cases of Massachusetts and England, both of which have reliable vital statistics going back to the mid-19th century. First we plot the infant mortality rates for each polity, and then their infant sex ratios.

Panel A of Figure 4 plots the IMR series for England and for Massachusetts from 1860 to 1990, including lines representing the 3-year moving average of the plotted (annual) values. The conformity between the two series is remarkable. Different trends might be discernible before 1900,[26] but two patterns are critical for our purposes. First, infant mortality was high and not falling in the period 1860-1900. Second, starting at the turn of the century, infant mortality rates trace a sharp downward path.

Following from the demographic theory laid out in section 2.1, the collapse of infant mortality shown in Figure 4 is predicted to cause a sharp decrease in the ratio of girls to boys among infants. As the toll of infant mortality faded across the 20th century, the female mortality advantage would have lost its force and infant sex ratios would increasingly reflect sex ratios at birth.

Panel B of Figure 4 plots the ratio of girls to boys for each polity (age 0 for England, ages 0 and 1 for New England). As predicted, the steep decline in infant mortality after 1900 is marked by a sharp decrease in the ratio of girls to boys.[27] Panel C of Figure 4 plots the ratio of girls to boys against the infant mortality in log terms. We observe a close relationship between the two when infant mortality is above 30 deaths per 1000 infants. For very small rates of infant mortality, a negligible number of infants are dying, meaning that infant mortality has no discernible effect on infant sex ratios.

In sum, the cases of England & Wales and of Massachusetts, which offer data on both infant mortality and infant sex ratios, provide strong corroboration of our claims that infant sex ratios can offer insights on infant mortality. The well-documented collapse in infant mortality observed in these polities was accompanied by – and caused by, in our view – a pronounced shift away from

---

Based on US census data, infant sex ratios for Blacks had a distinct female bias, relative to health ratios at birth, and compared to whites. For example, among children under-two, the number of girls per 100 boys was at least 3.9 greater for Blacks than whites at every census benchmark from 1900 to 1980. That racial sex-ratio gap is one more piece of evidence on the striking racial disparities that have plagued the US for centuries. Although the racial sex-ratio gap shrank after 1980, it remains large (1.8 points in 2010).

[25] HMD births data shows the US sex ratio at birth changing from 94.9 girls to 100 boys in 1950 to 95.3 in 1960, which could account for almost 1/2 of the shortfall between the census value and the model prediction.

[26] For Mass, we see a two-part path, the IMR rising in the 1860s, followed by a plateau. For England, we see a very shallow U-shape, with the IMR rate tending to sag in the 1860s and 1870s, and rise in the 1880s and 1890s.

[27] This pattern is particularly evident in England. In Massachusetts, the data is noisier, a reminder of the large sample sizes needed to make inferences from infant sex ratios.

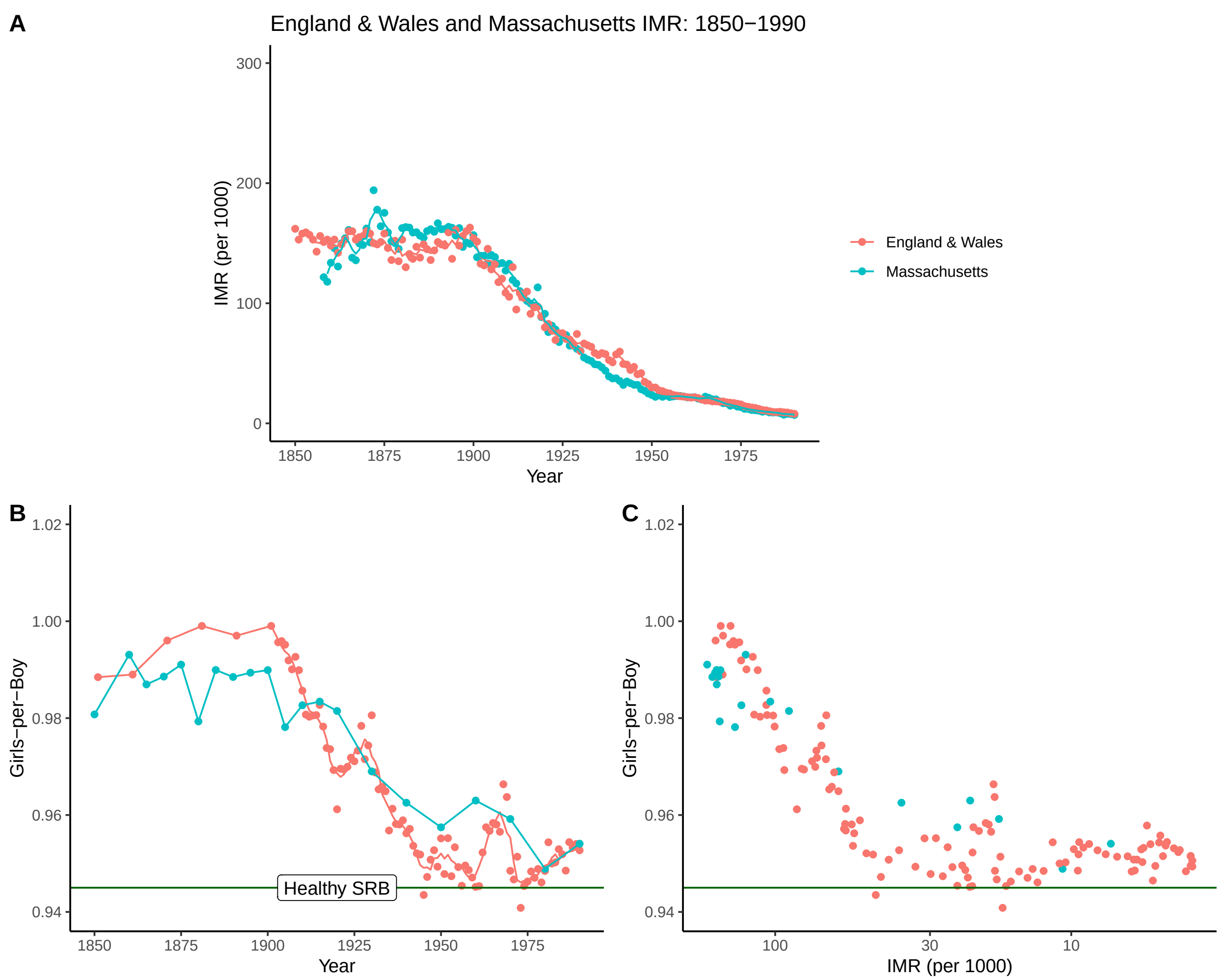

Figure 4: Panel A: England & Wales, and Massachusetts infant mortality rate, 1850-1960. Panel B: Ratio of girls to boys ages 0 to 4 in Massachusetts and age 0 in England. Panel C: Ratio of girls to boys by infant mortality rate. The green line in panels B and C represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls). Source, HSUS and US census for Massachusetts; Record Group 69 for England & Wales.

girls in infant sex ratios. Because of the female infant mortality advantage, the early 20th-century collapse in infant mortality saved boys more than girls.[28] Panel A's declines in infant mortality are reflected in the sharp shift toward males Panel B's sex ratios. The underlying relationship – increasingly female-biased sex ratios with higher rates of infant mortality (and worsening maternal-infant health) – is well-represented in Panel C. In Panel C, we see that when infant mortality is not low, reductions in infant mortality push infant ratios by away from girls. These two cases provide proof of concept, pointing to the promise of infant sex ratios for revealing broad patterns of infant mortality when vital statistics are lacking.

2.4 Potential Concerns

While infant sex ratios offer great promise as indicators of maternal-infant health, they have several key limitations. Most importantly, sex discrimination against girls means that infant sex ratios offer a fundamentally one-sided test of maternal-infant misery. A healthy-looking sex ratio could simply reflect mortal sex-discrimination that pushes sex ratios toward boys. Sex ratio evidence must be interpreted in light of gendered social norms and practices, because mortal misogyny – such as female infanticide and mortal neglect – will skew infant and child sex ratios towards boys. Comparisons of infant sex ratios must not be naively interpreted as evidence on comparative health conditions, without considering the potential role of sex discrimination.[29] Because societal gender discrimination operates against girls, not boys, it creates a male-bias in sex ratios – a male-bias that could reverse the effects of high infant mortality. It follows that female-biased sex ratios are an unambiguous sign of poor maternal-infant health, but apparently healthy infant sex ratios could simply reflect high infant mortality obscured by mortal misogyny (fatal sex discrimination). To guard against that possibility, it is important to check sex ratios at older ages. In general, mortal misogyny is evident in a pattern of very male-biased sex ratios after infancy.[30]

In addition to the effects of gendered social practices, there are several practical limitations to the use of infant sex ratios as indicators of maternal-infant health. First, large sample sizes (tens of

[28] Probably sex ratios at birth also shifted away from girls in the period, with improvements in maternal health reducing relative male fetal loss, but evidence here is lacking

[29] To take one dramatic example: the 1891 British Census of India reported for the "Panjáb Province" an under-age-two population (of over 1.5 million) with 95.3 girls per 100 boys, which might be viewed (naively), as interesting evidence of favorable maternal-infant health (especially in contrast to the England & Wales in 1891, with 101.3 girls per 100 boys in 1.4 million under-twos). But the Panjáb's population aged five to nine had 84.7 girls per 100 boys (compared to 100.5 girls per 100 boys in England & Wales in that age-group). On our reading, the male-biased 1891 sex ratios for the Panjáb reflect mortal misogyny ("missing women"), and are not informative of maternal-infant health. On the other hand, we view the female-skewed sex ratios in England & Wales at the time as indicator of high infant mortality there (on which, see below). The sex ratios are calculated from Census of India 1891:98-100 and 1891 Census of England & Wales (1893 Vol III page v).

[30] See the prior footnote for the extreme sex-ratio values in 1891 in the Panjáb Province of India. With attention to broader historical knowledge, and to sex-ratio evidence, we can often be quite confident that mortal misogyny was not a factor in observed sex-ratio patterns. However, there remains an asymmetry in inferring bad versus good conditions of maternal infant- health: in this world where societal gender discrimination is against girls and women, female-biased infant sex ratios are an unambiguous sign of bad conditions; male-biased infant sex-ratios could reflect good conditions or mortal misogyny.

thousands) are needed for a sex ratio to have reasonably sized confidence intervals.[31] Second, small changes in infant mortality may prove difficult to discern from infant sex ratios due to random variation in the sex ratio at birth. Third, infant sex ratios are also vulnerable to sex-biased age heaping. In order to combat these concerns, we focus our attention on the sex ratios for ages 0 and 1 and 0 to 4. Our evidence of sex-biased age heaping in the US census is discussed in the appendix (section 8.1).[32]

3 North American Infant Mortality: 1850-1920

In this section, we apply infant sex ratios as an indicator of North American infant mortality from 1850-1920. As discussed in section 1.1, we lack vital statistics for most of North America before the 1920's, and patterns of infant mortality are particularly unclear for the 19th century. Was infant mortality high or low relative to contemporary Europe? Did infant mortality increase or decrease across the period? Evidence from infant sex ratios promises to reveal the broad contours of infant mortality change – and requires only published census data, rather than vital statistics.

3.1 Existing Estimates of US IMR

Lacking direct evidence (vital statistics) on infant mortality for the 19th-century US, current IMR estimates come from life tables, built from a range of demographic evidence and theory. Most influential in our eyes are those of Haines (1998),[33] which form the basis for the Historical Statistics of the US (2006) infant mortality series for the period 1850 to 1910.[34] Henceforth we refer to those

[31] Recalling that a healthy modern population's under-two sex ratio will be about 95 girls per hundred boys, consider an observed sex ratio of 97. With 10,000 children the 90% confidence interval is about 93.9 to 100.3 girls per hundred boys; with 50,000 children the 90% CI shrinks to about 95.7 to 98.5 (treating the sex-proportion as a binomial random variable – see e.g. Visaria 1967:133). In the smaller population, the female-biased sex ratio is inconclusive as evidence of poor maternal-infant health. This example is a heuristic device, if only because ours is not an exercise in statistical inference. If it were, we would consider the asymmetry of relevant confidence intervals. In the context of maternal-infant ill-health, the concern is female-biased sex ratios; but for research on mortal misogyny ("missing women"), the concern is male-biased sex ratios.

[32] In our experience, the aggregation involved in under-two and under-five sex ratios dampens spurious variability evident in single-year ratios. As an example, the 1880 census counts at ages 0 to 5 include single-year sex ratios that range from 96.6 (age 2) to 98.1 (age 3) girls per hundred boys. But the under-two and under-five values are almost the same: 97.15 and 97.10 girls per hundred boys. We interpret the 1.5 point difference in the sex-ratio values for ages 2 and 3 as some combination of age-heaping and random variation, and not a reflection of differential mortality experiences at the two ages. Using under-two sex ratio also serves to correct for problems of male-biased age-heaping at age 1, which we often find in US census data, as discussed in the appendix. Note that we might expect under-enumeration of young infants, but with a presumption of son-preference, that should be reflected in male-biased sex ratios at age 0 (not at age 1).

[33] Hacker (2010) produces new decennial life tables for the US white population, updating Haines's methods to better account for the changing shape of life-cycle mortality across the 19th century. The levels of infant mortality in Hacker's (2010) life tables are broadly similar to Haines's estimates.

[34] HSUS series Ab9, Ab10, Ab920, and Ab921 are almost identical to the life-table infant mortality rates in Haines (1998:156-68). There is some confusion in the dating of the 1900 and 1910 IMR estimates: a footnote to HSUS series Ab9 and Ab10 says "For ... the infant mortality rate, the values for 1900 and 1910 are from approximately 1895 and 1904, respectively" but that clarification is not provided for Series Ab920 and Ab921, where the 1900 and 1910

estimates as Haines/HSUS (1998, 2006).[35]

Figure 5 presents current estimates and data for US infant mortality across the period 1850 to 1960, which are by represented 4 plots.[36]. From the mid-1920s onward, the IMR values are presumed to be reliable, at least for orders of magnitude; from 1933 onward they are vital statistics data (historical "facts" perhaps). The IMR estimates for the US are increasingly speculative moving back in time.[37] The Haines/HSUS (1998/2006) series offers estimates at census benchmarks for 1850 to 1910. Bell & Miller's (2005) life tables provide estimates at census benchmarks starting in 1900 (and those reflect vital statistics data, once available). The third plot (BRA) shows IMR data for the Birth Registration area of the US, which started in 1915 with 4 states, expanding to cover the entire country by 1933 (Vital Statistics 1950:8-10). Finally, from 1933 onward the vital statistics series is plotted. We frame these US estimates with values from contemporary Europe, including the IMRs of Norway, England & Wales, and Austria from the mid-19th century until the US vital statistics era.

Figure plots the estimated values of the infant mortality rate (IMR) in the US from the Haines/HSUS (1998/2006) and Bell & Miller's (2005) life-table estimates for IMR for 1900 to 1960.[38] We frame these estimates with values from contemporary Europe, including the IMRs of Norway, England & Wales, and Austria from the mid-19th century until the US vital statistics era.[39]

As seen in Figure 5, these existing estimates for the US tell a fairly simple story: that mid-19th-century US infant mortality was high by European standards, and that it declined substantially across the second half of the 19th century (and continuing to fall in the 20th century, in the period prior to US vital statistics).[40] According to the HSUS estimates, the US infant mortality rate was almost as high as Austria's in the 1850s, before falling to English levels by circa 1890.

Such a picture of American infant mortality is very surprising, in two regards. First, substantially higher rates of infant mortality in the US than in England at mid-century will strike some as

IMR values are the same as in Ab9 and Ab10. However, that is a very minor issue in the context of the very different view of US infant mortality the we develop in this paper.

[35]We adopt this notation to distinguish these IMR estimates from those which are from US vital statistics, which comprise the HSUS series starting in 1933. As noted above with reference to Figure 1, the HSUS IMR series from 1924-1932 covers over 75% of the US population, so those values can be relied on for orders of magnitude.

[36]Note that we denote the IMR as "data" when it comes from Vital Statistics that are judged to be reliable, reserving the term "estimates" for IMR values with a less-solid empirical basis. That dichotomy too strong, but it serves to simplify

[37]The three series that we denote Haines/HSUS, BRA, and VS together make up Series Ab920 of Historical Statistics of the US (2006).

[38]Looking ahead, our results suggest 19th-century US infant mortality was an order of magnitude lower than the estimates of Haines/HSUS (1998/2006). It bears emphasis that Haines was not seeking to estimate infant mortality: the estimates fall out of life tables which built from well-regarded data on older child and teenager mortality.

[39]The 3 cases are suggestive of the range of European infant mortality experiences (see Figure 1 for the full range).

[40]"Fairly simple" because the spike in infant mortality in 1880 interrupts an otherwise simple pattern of decline. Hacker (2010:65) discusses the Haines's result for 1880, allowing for the possibility that "1880 was a particularly unhealthy year" but providing evidence which suggests the apparent deterioration in mortality is "an artifact of differential census enumeration".

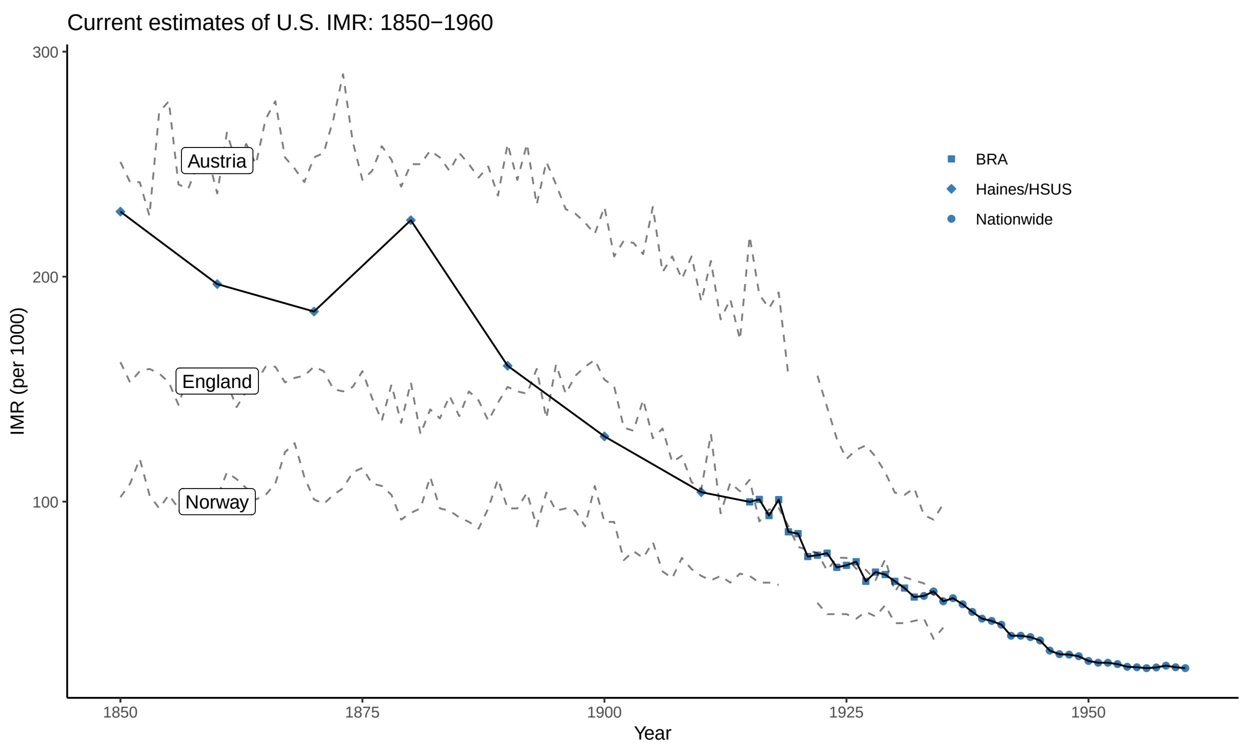

Figure 5: US Infant Mortality Rates, 1850-1910: conjectures, estimates and data. Sources: HSUS (2006), Bell and Miller (2005). From 1914 to 1933, IMR data from the BRA. From 1933 onward, IMR data from nation-wide vital statistics. European data from International Historical Statistics (1998).

implausible.[41] The US was much less urbanized than England & Wales (one-fifth vs one-half),[42] and a substantial body of research documents an urban mortality penalty in the 19th century.[43] With even a modest urban penalty in terms of infant mortality, we might expect the US infant mortality rate to be some 20 points below the English value – and certainly not above it.[44]

Second, the suggested timing of US infant mortality decline stands out as exceptional. It is around the turn of the 20th century that we observe the start of substantial sustained improvements in infant mortality in a wide range of cases for which we have good data, including England, France, Belgium, Norway, and Massachusetts.[45] Moreover, the US underwent substantial urbanization between 1860 and 1900 (from one-fifth urban to two-fifths), which should have driven up the infant mortality rate.

3.2 US Sex Ratios: 1850-1990

In Figure 6 we plot sex ratios at census benchmarks from 1850 to 1990 for the US populations under two years of age and under five years of age, based on US census data., based on US census data. Because of problems with the 1890 census data, we treat the sex ratios for that year as "missing values" for the purposes of our discussion and presentation (but 1890's anomalous values are show in Figure 7).[46]

[41] Referring to emerging debate on the standard of living in the US, Engerman (1997:18) observed that "such a controversy would have seemed rather more surprising to residents of early-19th-century New York than to residents of London at the same time." In our view, a similar point might be made with reference to a comparison of infant mortality among the US free population and the people of England during the mid-19th century.

[42] The urban share of population in the US in 1860 was just under 20% (Wilkie 1976:144,146). In England in 1851 it was 54% (Woods 2000:362). In both the cut-off for urban is 2,500 people.

[43] On the 'urban penalty', see for example Kearns 1988; Woods 2000; Haines 2001; Cain and Hong 2009; Eggerickx, Debuisson, and Sanderson 2012; Davenport 2020.

[44] The orders of magnitude are illustrated by supposing the two places differed in urbanization but not in rural and urban IMR values. Then the difference in IMRs across the two is simply the product of (the difference in their urban shares) and (the difference in the urban and rural IMR values). With England & Wales 34% points more urban than the US (circa the 1850s) and an urban IMR penalty of 60 points, the simulation suggests the US IMR would be 20 points below England's (which was around 150). A 60-point urban IMR penalty seems a modest value, based on Davenport's research (2020:465,467), which indicates urban IMR values over 180 and rural values under 120 for England & Wales. More dramatically, Woods (2000:260) builds infant life tables for Victorian England & Wales; those have an urban infant mortality penalty of 115 points (the rural IMR is 97 and the urban is 218, for an overall rate of 150). For the US, Haines reports IMR values (2001:59) with an urban penalty of over 140 points in 1890, looking across 7 states in the northeastern US.

[45] Looking ahead, it seems the US followed the European pattern, with a pronounced decline in infant mortality coming after 1900. Recalling that the Haines/HSUS (1998/2006) infant mortality rates come out of life tables, it is worth noting that early childhood (ages 1-4) mortality in England exhibits a fairly consistent decline across the second half of the 19th century. Standard life tables would predict the same trend in infant mortality.

[46] The sex-ratio evidence for 1890 is inconclusive because of data problems. The 1890 census manuscripts have not survived, so there is no full-count IPUMS data. Values of the under-2 ratio from the published 1890 census volumes are skewed toward males, relative to the under-5 values. In 1890 the national under-2 ratio was more than 0.5 points more male the under-5 (95.97 vs 96.52); in all other census years, that gap was at most 0.2 points. The male-biased under-2 values reflect problems with the enumeration of ages. As discussed in 1900 and 1910 census reports, only the 1890 census asked for "age at nearest birthday" instead of "age at last birthday", which was used from 1850 to 1880, and from 1900 forward (page xlviii of Twelfth Census (1900), Census Reports Volume II, Population Part II, Washington: GPO, 1902). A general pattern of male-biased under-2 values is evident across states and cities in 1890, and we confidently set aside under-2 values for 1890 as implausibly male. To a lesser extent, 1890's under-five

The infant-sex-ratio values for the 19th-century are distinctly more male than those of the early 20th century, a finding which contradicts the existing estimates of US infant mortality, which show a substantial decline in infant mortality from 1850-1900.

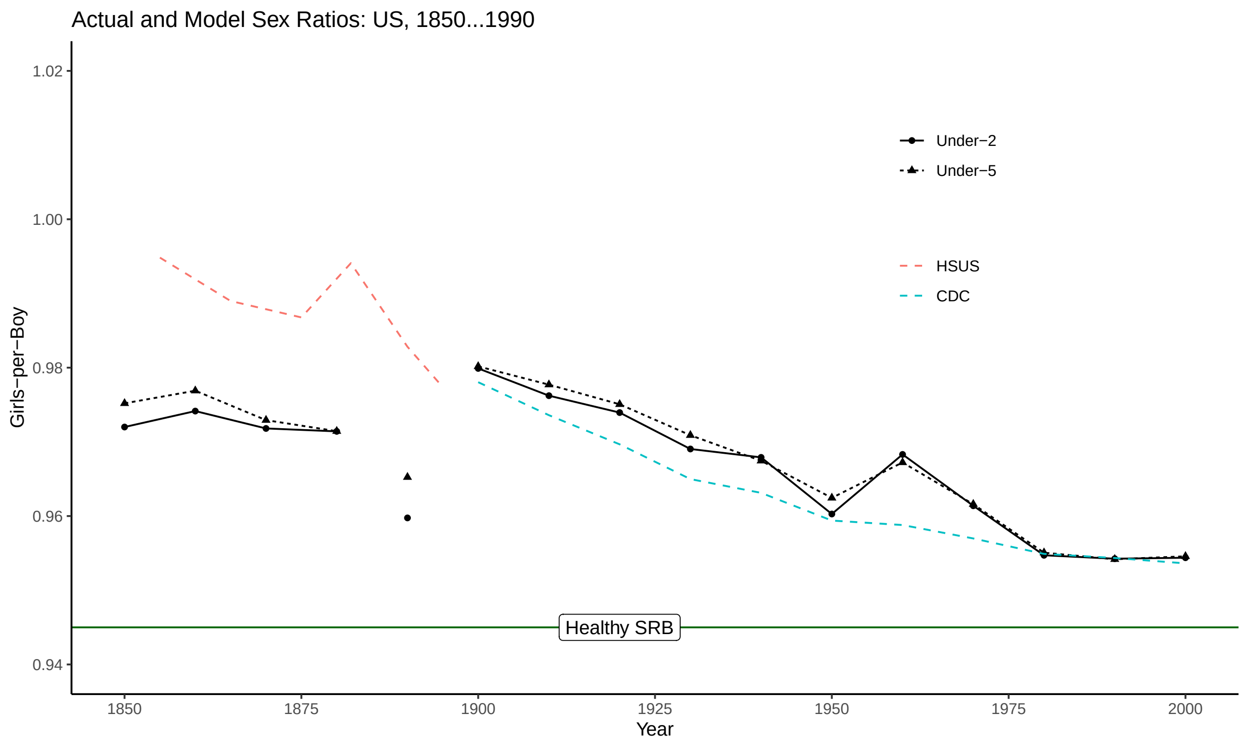

Figure 6: The ratio of girls to boys, ages 0 and 1: US 1850-1940. Source, the US Census: an average of the PUMs and published Census Volumes. The 1890 census is anomalous, and therefore we leave it out from the line series. The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls). Dashed lines are model sex ratios based on Bell and Miller (2005) and the HSUS (2006).

Figure 6 also presents a set of heuristics which highlight the contradiction between our sex-ratio evidence and the existing estimates of US infant mortality 1850-1900. We plot two sets of model infant sex ratios, illustrating expected sex ratios given infant mortality estimates. The blue model line, labeled B&M, is the Bell and Miller model sex ratio, reproduced from Figure 3, showing the ratio of girls to boys ages 0 and 1, based on the Bell and Miller life-tables. The red line corresponds to the IMR estimates of the Haines/HSUS. The Haines/HSUS line is an extrapolation from the Bell & Miller line, based on the relationship between infant mortality and infant sex ratios in "West" model life tables, taking the IMR rates from the Haines/HSUS.[47] Different life-table models would yield different slopes to the model sex-ratio lines, but the biology of excess male infant mortality

values also seem implausibly male-skewed, but more in-depth attention to state and city-level patterns is required to identify the nature and magnitude of any biases.

[47]The HN model lines is calibrated to the Bell & Miller line; it is lower than the early B&M line because the Haines/HSUS IMR estimates are below those of Bell & Miller. The model lines are extrapolated off of the Bell & Miller line, using slopes of the ratio of girls to boys with respect to IMR, which we calculate from the West model

generates the prediction that degree of female-skew in the infant sex ratio should, like the IMR, start out high and then decline.[48]

The pattern of sex-ratio values found in Figure 6 sharply challenges the validity of existing estimates of US infant mortality. The sex-ratio values for the period 1850 to 1880 are much *less* female-biased than those for the turn of the century. The simple strong implication is that maternal and infant health and well-being were substantially better circa 1850-1880 than circa 1900-1910.[49]. Based on the current estimates of US infant mortality across the period 1850 to 1910 (Figure 5), we would predict female-biased sex-ratio values during the relatively high mortality regime of the 1850s to 1880s, with less female-bias to the sex ratios at the turn of the century, when mortality estimates are lower. Put simply, the sex ratio (girls per boy) is predicted to move in the same direction as the infant mortality rate –lower infant mortality results in fewer girls per boy in the population.[50].

Figure 7 offers an additional perspective on the Haines/HSUS IMR estimates, plotting observations of under-two sex ratios (girls per boy) by infant mortality rates (in log terms) for the US, Canada, New Zealand, England & Wales, and the state of Massachusetts.[51] As predicted by the theory in section 2.1, there is a close relationship between the two: as infant mortality decreases, we see relatively fewer girls in the population, because mortality reductions save more boys than girls. The Haines/HSUS estimates are marked as triangles. While the triangles furthest right, the estimates of IMR for 1900 and 1910, are not exceptional, those for the 19th century are clear outliers. We conclude that while Haines/HSUS estimates of IMR are not implausible back to 1900, those for the 19th century should be revised downwards.

3.3 Conjectured IMR

We conclude our discussion of the US as a whole by offering conjectural estimates of infant mortality at census benchmarks for the period 1850-1880 and 1900-1930, presented in Figure 8. The conjectural estimates fall out of a simple curve-fitting exercise, which describes the relationship between the under-five sex ratio and the natural log of the infant mortality rate. We use simple regressions with nine observations from North America which have reliable infant mortality data and relevant

life tables. The extrapolation is piece-wise linear, as we calculate slopes at different levels of IMR. The slopes from the West model are smaller-size than those in the Bell & Miller life tables or the UN's "General" model life tables, making our chosen curves relatively conservative for our purpose.

[48]Our focus on the female mortality advantage reflects our maintained hypothesis that variation in sex-discrimination was not generating sex-ratio variation. The sex-ratio decline we observe in the later 19th-C US could also have resulted from reductions of misogynist discrimination (reducing excess female mortality and reducing the ratio of girls to boys), with no implication for the IMR. To our best knowledge, there is no evidence of "missing women" from the US in this period, so we read these changes as having to do with maternal-infant health.

[49]Of course other interpretations could be proffered; see footnote above, which discusses issues of male-biased sex ratios

[50]Recall the logic: because of the female infant mortality advantage, reductions in infant mortality save more boys than girls, pushing the sex-ratio away from girls

[51]Note that infant mortality is declining along the x-axis, to facilitate comparison to our figures, where the x-axis is time, and IMR tended to fall with time.

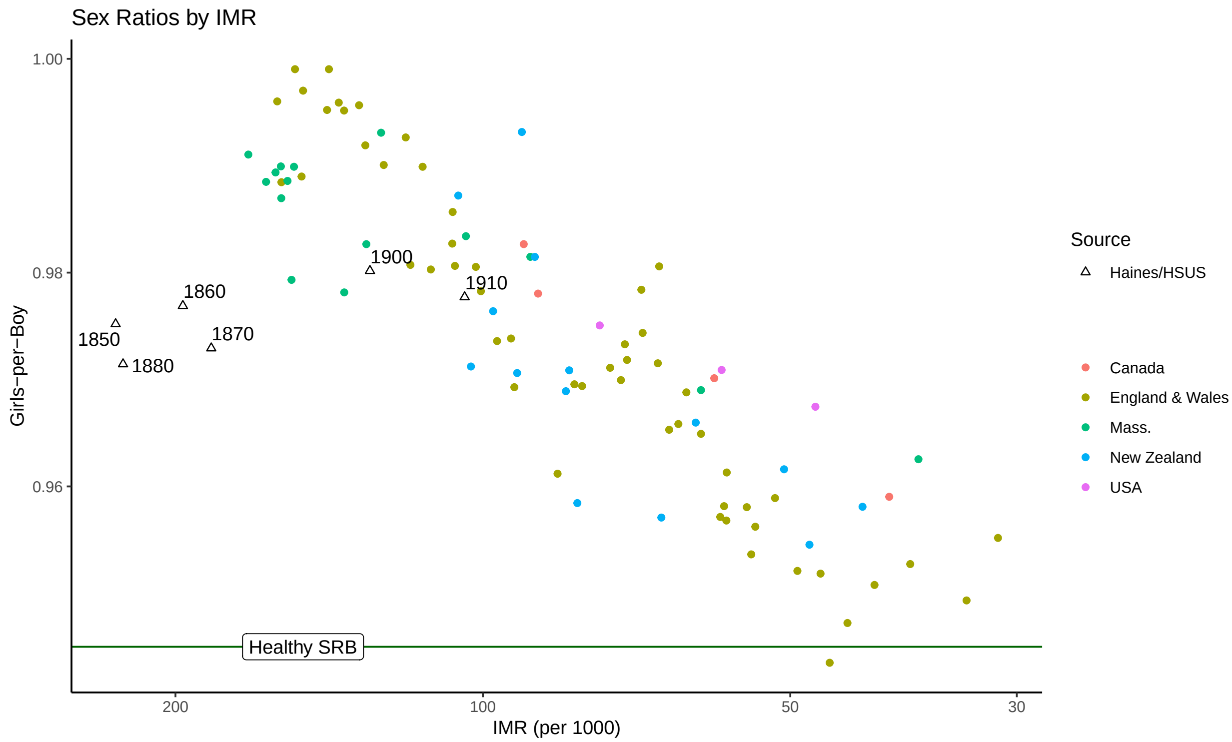

Figure 7: Infant sex ratios (girls per boy) by infant mortality, for the USA, England & Wales, New Zealand, Canada and Massachusetts. Observations are limited to an IMR of at least 30 deaths per 1000 infants. Data from the US and Canadian censuses, the HSUS (2006), Statistics Canada, and Record Group 69 for England & Wales. New Zealand IMR data from the census and the Digital Yearbook collection.

sex-ratio values.[52] We suppose that both the IMRs and the sex-ratio data are measured with error, so we fit two curves to the data (direct and reverse regressions).[53] Our conjectural estimates are the simple averages of the two fitted values (IMR predicted from the under-five sex ratio). The fitted lines can be found in Figure 16. In future research, we hope to incorporate a broader range of data into this analysis, in order to develop a more robust method for estimating IMR from sex ratios.

Our estimates are plotted as conjectures on Figure 8, and are on the order of 7% infant mortality. We report our conjecture as a percentage, rather than a rate per thousand infants, in order to emphasize the conjectural nature of these results. In our reading, infant mortality was relatively low in the mid-19th century, before increasing to levels similar to the healthiest parts of Europe (Norway) around 1900. Our findings further suggest that the current US estimates of IMR for 1900-1920 are somewhat too high, perhaps because the Birth and Death Registration areas, which they are based on, were not representative of the country as a whole.

3.4 Canadian Sex Ratios: 1850-1990

As in the US, we lack vital statistics for Canada before the 1920s, making the 19th century a "dark age" for the study of mortality in Canada (Pelletier et. al., 1997: 94). However, we do have child sex ratios from census data. Just as with the US, child sex ratios promise to reveal the rough patterns of infant mortality in Canada from 1870-1920.

In Figure 9 we plot the ratio of girls to boys ages 0 and 1 and ages 0 to 4 from the Canadian census for the period 1850-1990. We see that Canada follows the same basic pattern as the US. From 1850-1880, child sex ratios are relatively male, but from 1880-1900 they shift toward females. From 1900-1920, they remain relatively female. From 1930 onward, the child sex ratios shift towards boys, reflecting the well-documented reductions in Canadian infant mortality from 1920 onward. Just as in the US, child sex ratios suggest that Canadian infant mortality peaked at the start of the 20th century, and that infant mortality was relatively low in the mid-19th century. In order to conjecture a level of infant mortality for this period, we use the same method as for the US in section 3.3. For the period of 1850-1880, our conjectured IMR for Canada is on the order of 5%, before increasing to more than 10% by 1911. Again, we emphasize the conjectural nature of these values. They are meant to capture the order of magnitude of infant mortality, rather than serve as point estimates.

[52] The nine IMRs that we deem reliable are Bell and Miller's life-table estimates for 1930, 1940, 1950; the Haines/HSUS estimate for the US in 1930, the Massachusetts's state estimate for 1900, and the Canadian vital statistics values for 1921, 1931, 1941, 1951. Each of those IMR values is paired with the corresponding under-five sex ratio, from census data. Of course many more observations of infant mortality rates and sex ratios are available from the second half of the 20th century, but those feature sex-ratio values that are distinctly less female-biased than those from which we estimate IMR values (for the years 1850-1930).

[53] The direct regression is Ln-IMR on the sex ratio; the reverse regresses the sex-ratio on the Ln-IMR. With R^2 values over 93%, the two curves are very similar, as are the IMR estimates they produce.

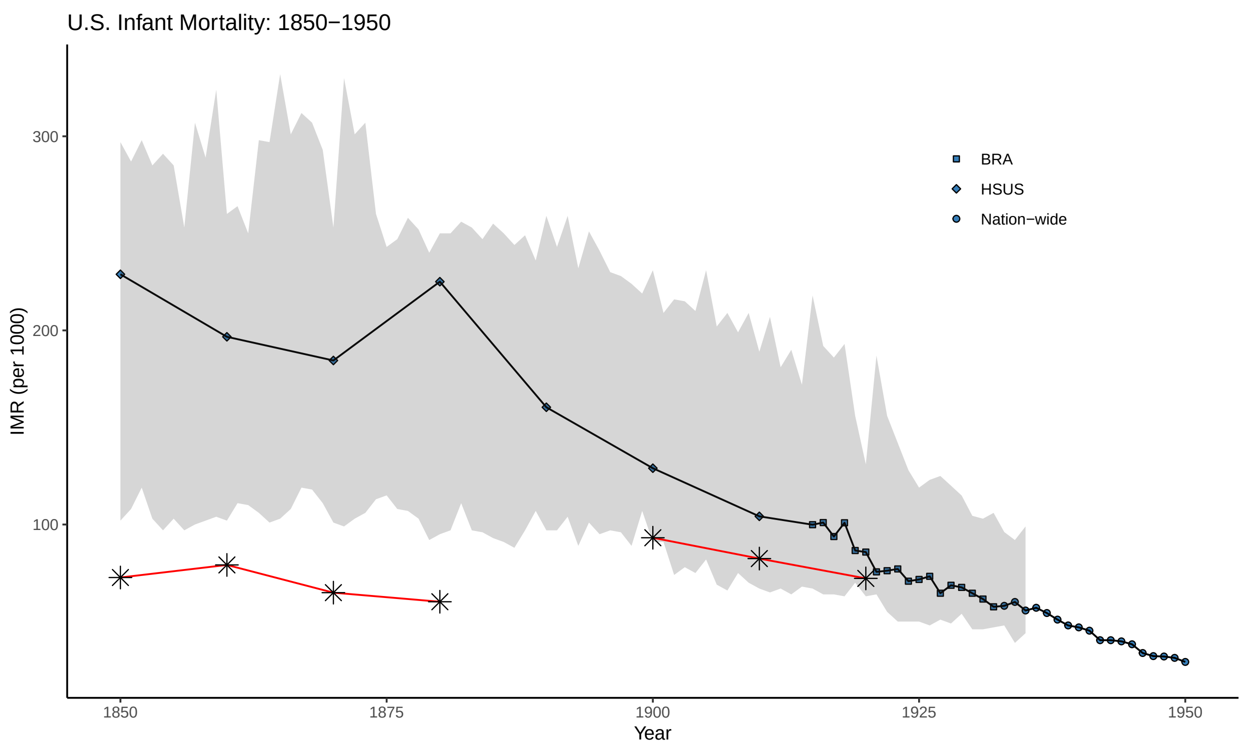

Figure 8: Conjectured US IMR for the period 1850-1880, based on infant sex ratios, black line: authors' calculations. Colored lines are the existing estimates and data for US IMR, from the HSUS (2006) and Bell and Miller (2005). The gray ribbon represents the range of IMR across selected European polities. European data from International Historical Statistics (1998).

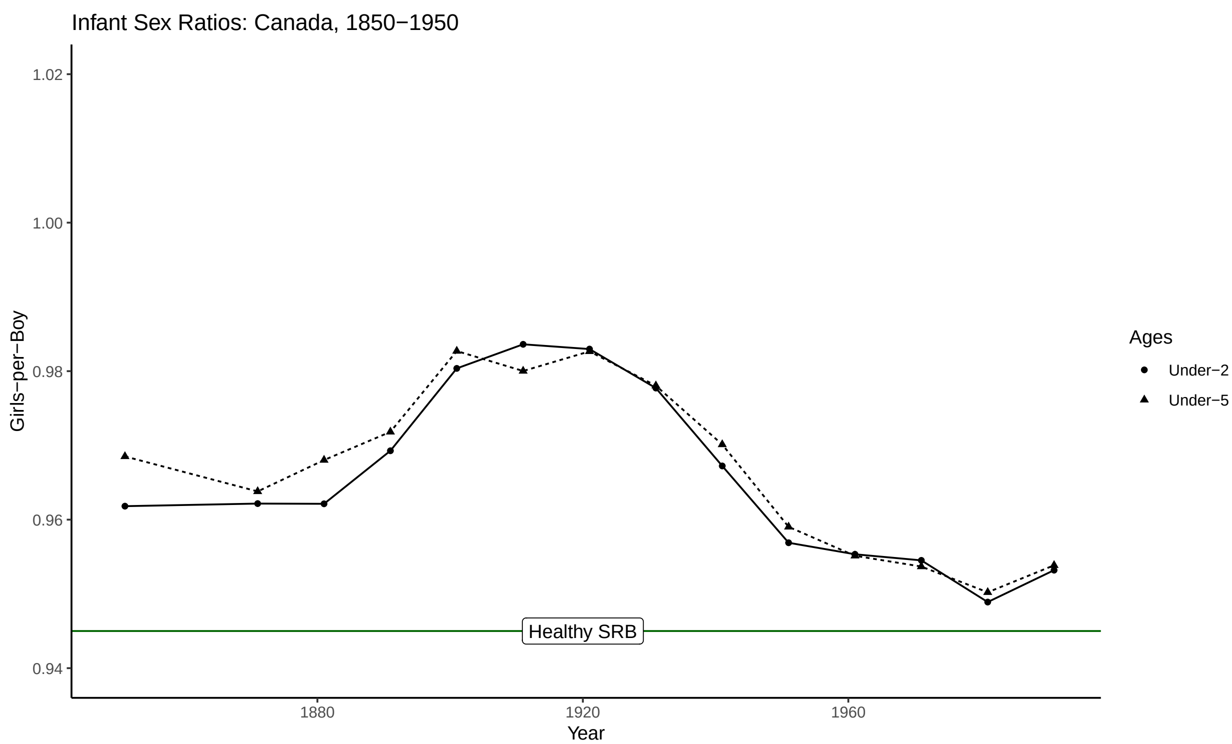

Figure 9: Ratio of girls to boys, ages 0 and 1 and ages 0 to 4: Canada, 1850-1990. The black line is the aggregate Canadian value. Data from the Canadian census, published census volumes. The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls).

4 Regional Patterns in North American Sex Ratios: 1850-1920

At the national level, sex ratios provide powerful evidence that North American infant mortality increased during the late 19th century, adding another dimension to discussions of the substantial health costs which were associated with the industrial revolution (Engels 1845, Komlos 1998). However, national aggregates tend to obscure regional differences in key determinants of contemporary health, especially urbanization and race, particularly in the case of the US.

Table 1 presents a summary view of the regions at selected census benchmarks. In 1860 the northeastern US (New England and Mid-Atlantic) was already substantially richer than the rest of the country, in accordance with being more urban and industrialized. The East North Central (ENC) was nearly as poor as the South Atlantic before the Civil War, but over the next nine decades the ENC pulled far ahead of the South Atlantic and caught up with the Northeast. After the Civil War, the South Atlantic, like the South generally, stood out for its relative poverty. For the country as a whole, and for our three northern regions, the second half of the 19th century saw tremendous economic growth, with per capita income increasing by a factor of more than 2.5 (quadrupling in the ENC). Moreover, the US as a whole went from around 10% urban in 1840 to 40% in 1900 and over 50% by 1920.

Table 1: Per capita incomes 1840-1950.

	1840	1860	1880	1900	1920	1930	1940	1950
Per capita income								
New England	2,190	3,065	4,586	5,803	6,665	7,968	9,228	12,045
Mid-Atlantic	2,256	2,936	4,586	6,020	7,203	8,647	9,457	12,818
MidWest (ENC)	1,112	1,479	3,317	4,591	5,805	6,856	8,541	12,376
South Atlantic	1,161	1,393	1,464	1,949	3,171	3,459	5,262	8,177
USA	1,659	2,143	3,252	4,331	5,375	6,177	7,626	11,050
Urbanization								
USA	10.8%	19.8%	28.2%	39.6%	51.2%	56.1%	56.5%	64.0%

Source: Easterlin (1961, p. 528) for regional and HSUS Ca11 (3-year averages) for national values. For urbanization, data from the US Census Bureau.

Attention to regional trends thus promises insight into the interaction of economic growth, urbanization and health. Improvements in material conditions may have improved maternal-infant health through nutrition, contributing to a decline in infant mortality. At the risk of oversimplification, we denote that perspective as the "McKeown thesis," for research attributing mortality declines to income growth.[54] On the other hand, infant mortality was greater in urban than rural areas well into the 20th century (Kearns 1988; Haines 2001).

4.1 US Sex Ratios by Census Division: 1850-1940

We take a regional decomposition of the eastern US: New England, the Mid-Atlantic, the South Atlantic and the East North Central. In Figure 10 we plot the ratio of girls to boys ages 0 and 1 and ages 0 to 4.

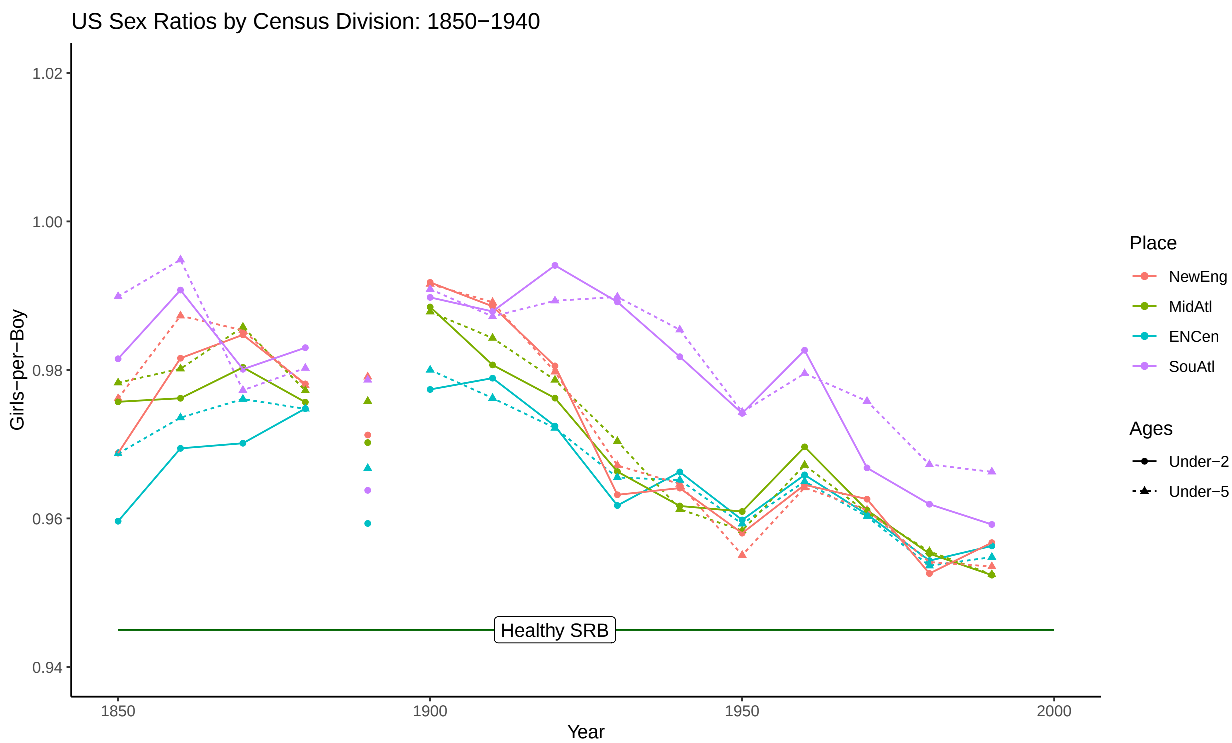

Figure 10: Ratio of girls to boys: US 1850-1990, by census division. Source, the US Census: an average of the PUMs and published Census Volumes. The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls).

[54] See Colgrove (2002) and references there; see also Fogel (2004).

In Figure 10, we see several basic patterns:

1. Infant sex ratios were most female-skewed from 1900-1910, suggesting that infant mortality was greatest around the turn of the 20th century;
2. From 1850-1880, infant sex ratios were relatively male-skewed, suggesting that infant mortality was relatively low;
3. From 1910 to 1990, the sex ratios trended back towards boys, reflecting the long, steady decline in infant mortality; and,
4. From 1850 to 1900, sex ratios were most male-skewed in the East North Central, suggesting that infant mortality was lowest in the poorest of the northern regions.

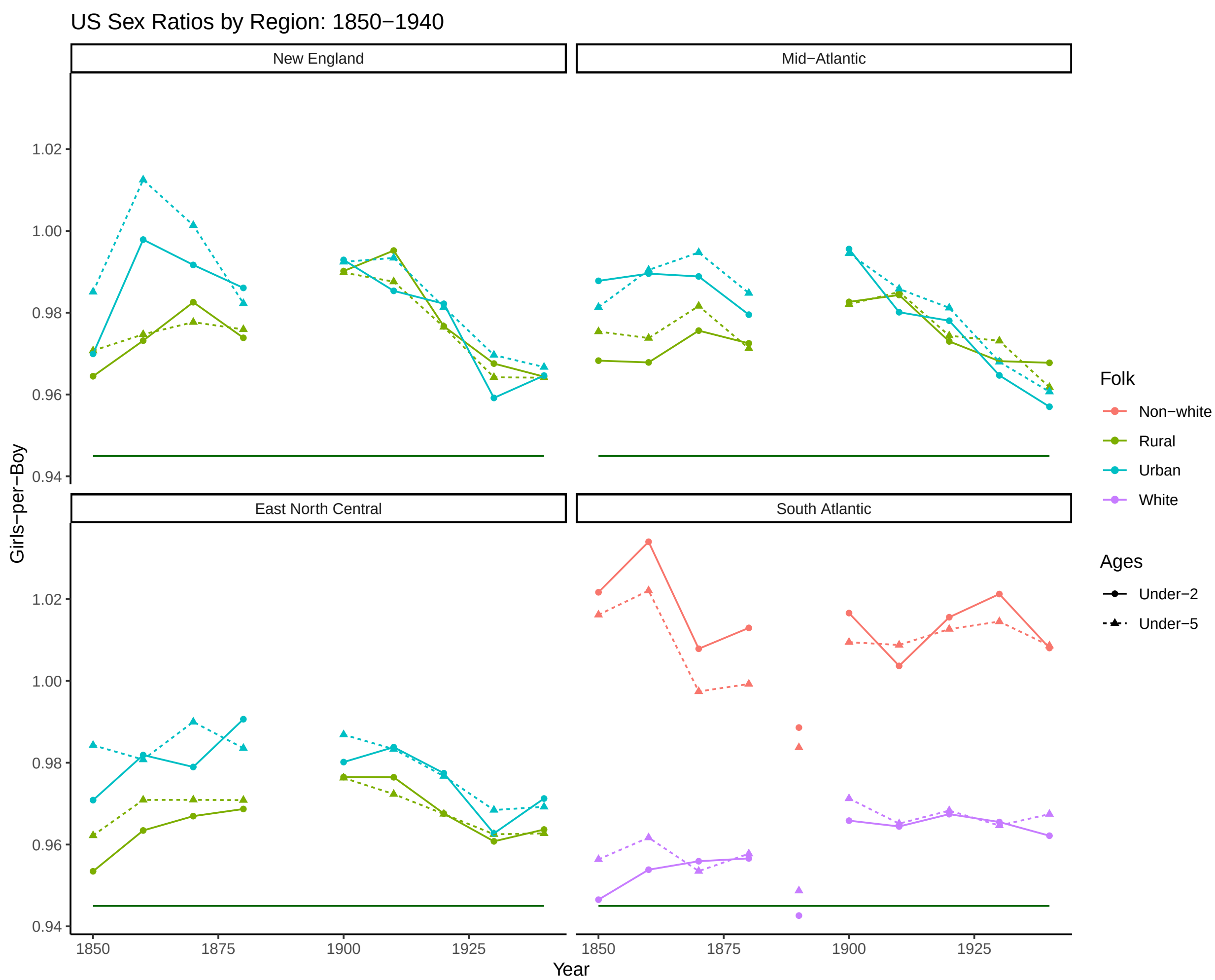

Figure 11: Ratio of girls to boys: Eastern US 1850-1940. Northern regions are cut by urban-rural, while the South Atlantic is cut by race. Data from PUMS. The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls).

In Figure 11, we plot infant sex ratios by urban-rural status for the northeastern regions, and by race for the South Atlantic. We observe:

1. From 1850-1910, the sex ratios were more female-skewed in urban than rural areas, likely reflecting higher infant mortality in cities;
2. This urban-rural gap in the north is dwarfed by the white-black disparity in the South Atlantic.

In contradiction to the "McKeown thesis", the rich, northeastern regions of the US had the highest ratio of girls to boys, while the relatively rural and poor East North Central had the lowest. Part of this pattern appears to be due to the relative lack of urbanization in the East North Central, as urbanization led to increased infant mortality, which would have culled male infants from the population. In the South, the pattern was dominated by extreme disparity between a miserable black population and a apparently healthy white one. Because of our interest in the joint effects of economic growth and urbanization on health, we will leave further discussion of the racial disparity in the South Atlantic to future research.

4.2 Canadian Sex Ratios by Province: 1850-1960

In Figure 12 we plot the ratio of girls to boys in Québec and Ontario. We find the same basic patterns as in the Eastern US, with child sex ratios the early 20th century being the most female, reflecting greater infant mortality. Regional patterns vary, with Québec sex ratio exhibiting a particularly sharp shift toward females from 1880 to 1900. After 1920, the sex ratio converge across the country and trend toward males, reflecting the well-documented decline in infant mortality in Canada during the 20th century. Explanation of this regional divergence is left for future research, but we note that the negative health consequences of late-19th-century economic growth appear to have been much harsher in Québec than Ontario.

4.3 Summary of Results

To conclude our results section, we see that sex ratios from across North America tell a consistent story: the ratio of girls to boys was relatively low in the mid-to-late 19th century, peaked in the early 20th century, and then declined thereafter. Taking sex ratios to be indicative of maternal-infant health, we observe that economic growth and health appear to have been inversely related before the 20th century.

5 Discussion

Evidence from infant sex ratios suggests that both the US and Canada had better maternal health in the mid-to-late 19th century than in the early 20th. As explained in section 2.1, females are

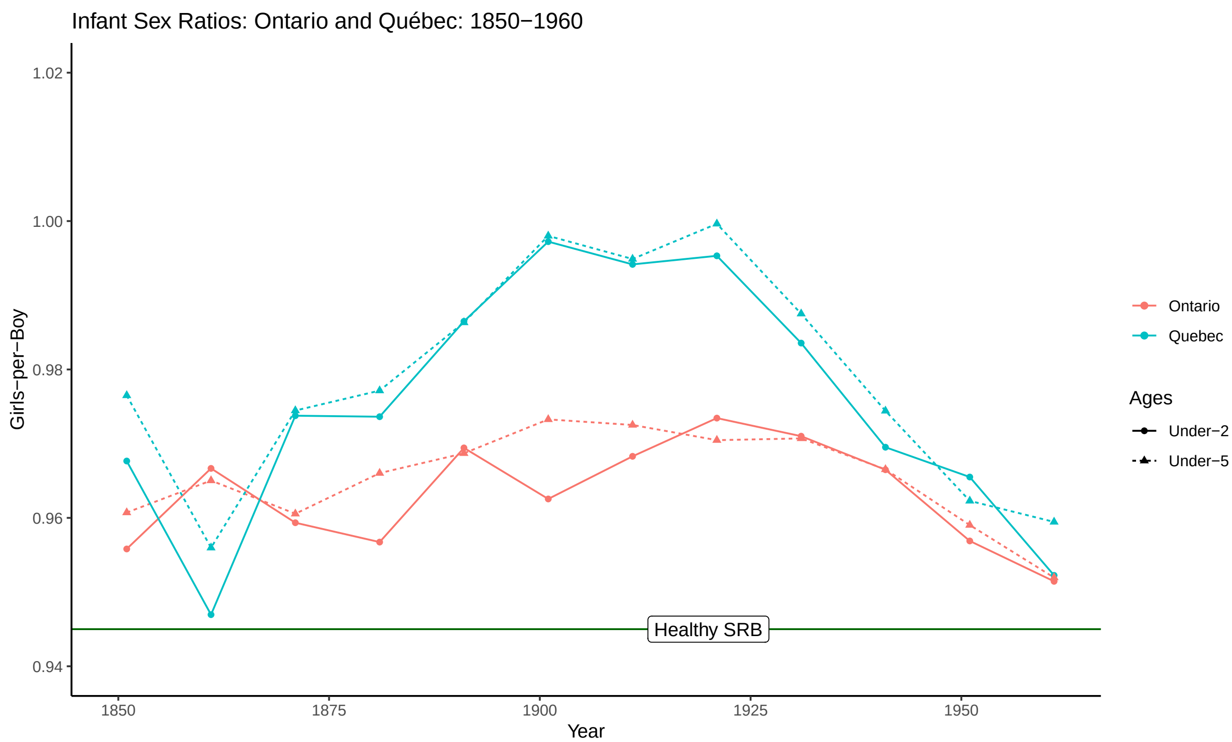

Figure 12: Ratio of girls to boys, ages 0 and 1 and ages 0 to 4 for Québec and Ontario: 1850-1960. Data from the Canadian census. The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls).

more resilient than males, meaning that high levels of infant mortality and poor maternal health lead to female-skewed child sex ratios. Across North America, child sex ratios were substantially more female in the early 20th century than in the mid-19th. We take this as evidence of poor maternal health and high infant mortality.

Our evidence suggests two major revisions to current estimates of US infant mortality.[55] First, the current estimates of US infant mortality are an order of magnitude too high for the mid-19th century. Rather than rates of 200 per 1000 infants, child sex ratios suggest that infant mortality was less than 100. In our reading, US infant mortality was substantially lower than that of England from 1850-1880. Such a finding should not be surprising, considering the large body of work documenting the "urban penalty" in 19th century (Preston and Van de Walle 1978; Haines 2001; Cain and Rotella 2001; Davenport 2020). England was mostly urban by 1850, whereas the US was only one-fifth urban in 1860. The current estimates of US infant mortality for the mid-19th century imply that *rural* infant mortality in the US was greater than *urban* infant mortality in England.[56] We find this implausible. Our conjectured IMR, on the other hand, fits well into existing knowledge of the 19th-century US as, by contemporary standards, a rural and therefore healthy place.

Second, US infant mortality *worsened* between 1850 and 1900. Existing estimates have found that US infant mortality declined from the mid-19th century onward. We find the opposite. Only after 1900 does infant mortality appear to improve across the US. In this sense, our results agree with the general pattern of infant mortality in Massachusetts and England, where substantial declines in infant mortality did not take hold until around 1900. More broadly, our results suggest that North American infant mortality followed a similar pattern as in much of Europe from 1850-1920 (Woods et. al., 1988: Table 1, page 349), with secular decline in infant mortality from around 1900, albeit starting from a lower level in the mid-19th century.

Our results do not contradict the well-documented decline in *child* mortality in the late 19th-century US, found by Haines and Preston (1991). Instead, we suggest that North America followed a similar pattern as identified in England by Woods et. al. (1988:350-351), with the decline in child mortality beginning several decades before that of infant mortality. Our results seem to affirm Alter's (1997:104) conjecture that in North America "child mortality declined two or three decades earlier than infant mortality." Indeed, the overestimation of infant mortality in the Haines/HSUS series for the period of 1850-1880 is likely due to a changing pattern of mortality, where adult and older child mortality declined while infant mortality stagnated or increased.[57]

We take urbanization and industrialization as the most convincing explanation for the deterioration

[55] For Canada our results line up better with existing estimates. Pelletier et. al. (1997: 96) give estimates of 90-100 deaths per 1000 infants for Québec in the 1850s and 1860s.

[56] Assuming an urban penalty of three-to-two (i.e. three urban deaths for every two rural) as found by Davenport (2020).

[57] Life-table estimates of IMR are essentially extrapolations of older child and teenage mortality. If child mortality declined, life-table estimates of IMR would also decline. Hacker (2010: 76) notes this "weakness" of life-table analysis, and calls for further research on the "changing relationship between infant, childhood and adult mortality" in the 19th century US.

in maternal infant health between 1850 and 1900, a view supported by the regional analysis in section 4. Urbanization meant greater infant mortality rates (Haines 2001), which would have culled boys from the population, making infant sex ratios more female. Moreover, industrial pollution has been shown to shift the sex ratio birth towards females (Sanders and Stoecker 2015), likely by increasing miscarriages. As cities invested in sewage systems and water treatment plants, urban health improved (Cain and Rotella 2001; Alsan and Goldin 2019), perhaps explaining our observed improvements in maternal-infant health after 1900.

Another key factor in the observed pattern of maternal-infant health may have been the role of milk.[58] The widespread adoption of cow-milk-based infant foods at the expense of breastfeeding, beginning in 1880, led to increased infant mortality (Wolf 2003:2000). From 1900 onward, milk pasteurization helped reduce the excess mortality of bottle-fed infants (Lee 2007). The issue of clean food for infants was particularly important in cities, as breastfeeding rates were lower (Preston and Haines 1991:29) and cow's milk less fresh relative to rural areas (Wolf 2003). Moreover, the effect of milk-based infant food may explain why infant mortality appears to increase during a period of declining child mortality.

More research is needed, but our results suggest a pessimistic view of the effect of industrialization and economic growth on maternal-infant health in the 19th century, followed by recovery in the early 20th. In this respect, our results agree with findings on stature in North America, which find deterioration across the second half of the 19th century (Cranfield and Inwood 2007; Steckel 2002).

6 Conclusion

In this essay, we have argued that child sex ratios are informative indicators of maternal-infant health. Furthermore, they are readily available for populations for whom infant mortality is not. Engerman (2003) highlights the "tensions between useful and measurable" indicators of living standards for historical populations. Child sex ratios are both.

Using new evidence from child sex ratios, we suggest two major revisions to current characterizations of US infant mortality. First, infant mortality rates in the 19th-century US were well below those of contemporary Europe. Second, infant mortality worsened in the US during the last quarter of the 19th century, increasing to levels typical of Europe. By our reading, the secular decline in infant mortality in the US did not begin until the turn of the 20th century. Canada appears to have followed a similar pattern.

Infant sex ratios provide yet another piece of evidence towards pessimism regarding the effects of industrialization and economic growth on living standards during the 19th century.[59] According to our evidence, North American maternal-infant health was better in the period of 1850-1880 than

[58] We thank Lou Cain for bringing this point to our attention.
[59] For example, see Komlos (1998).

in 1900, leading us to join the many critics of the “McKeown thesis”. Rather than following the inexorable push of progress, maternal-infant health appears to have moved inversely to economic growth for much of the 19th century, a result reminiscent of Easterlin’s (1999) conclusion that public intervention, not economic growth, have been responsible for the drastic improvements in health observed in the modern era.

7 References

Alkema, Leontine, Fengqing Chao, Danzhen You, Jon Pedersen, and Cheryl C. Sawyer. 2014. "National, Regional, and Global Sex Ratios of Infant, Child, and Under-5 Mortality and Identification of Countries with Outlying Ratios: A Systematic Assessment." *The Lancet Global Health* 2 (9): e521–e530.

Alsan, Marcella, and Claudia Goldin. 2019. "Watersheds in Child Mortality: The Role of Effective Water and Sewerage Infrastructure, 1880-1920." *Journal of Political Economy* 127 (2): 586–638.

Arbuthnot, John. 1710. "II. An Argument for Divine Providence, Taken from the Constant Regularity Observ'd in the Births of Both Sexes. By Dr. John Arbuthnott, Physitian in Ordinary to Her Majesty, and Fellow of the College of Physitians and the Royal Society." *Philosophical Transactions of the Royal Society of London* 27 (328): 186–90.

Bell, Felicitie C., and Michael L. Miller. 2005. *Life Tables for the United States Social Security Area, 1900-2100.* 120. Social Security Administration, Office of the Chief Actuary.

Brändström, Anders, and Lars-Göran Tedebrand. 1988. *Society, Health and Population During the Demographic Transition.* Vol. 4. Stockholm, Sweden: Almqvist and Wiksell International.

Cain, Louis, and Elyce Rotella. 2001. "Death and Spending: Urban Mortality and Municipal Expenditure on Sanitation." In *Annales de Démographie Historique*, 139–54. 1. Belin.

Catalano, Ralph A. 2003. "Sex Ratios in the Two Germanies: A Test of the Economic Stress Hypothesis." *Human Reproduction* 18 (9): 1972–5.

Catalano, Ralph A., Katherine Saxton, Tim Bruckner, Sidra Goldman, and Elizabeth Anderson. 2009. "A Sex-Specific Test of Selection in Utero." *Journal of Theoretical Biology* 257 (3): 475–79.

Catalano, Ralph, Tim Bruckner, Elizabeth Anderson, and Jeffrey B. Gould. 2005. "Fetal Death Sex Ratios: A Test of the Economic Stress Hypothesis." *International Journal of Epidemiology* 34 (4): 944–48.

Catalano, Ralph, Tim Bruckner, Jeff Gould, Brenda Eskenazi, and Elizabeth Anderson. 2005. "Sex Ratios in California Following the Terrorist Attacks of September 11, 2001." *Human Reproduction* 20 (5): 1221–7.

Catalano, R., T. Yorifuji, and I. Kawachi. 2013. "Natural Selection in Utero: Evidence from the Great East Japan Earthquake." *American Journal of Human Biology* 25 (4): 555–59.

Cipolla, Carlo M. 1978. *The Economic History of World Population.* Penguin.

Corsini, Carlo A., and Pier Paolo Viazzo. 1997. *The Decline of Infant and Child Mortality: The European Experience, 1750-1990.* Martinus Nijhoff Publishers.

Cranfield, John, and Kris Inwood. 2007. "The Great Transformation: A Long-Run Perspective on Physical Well-Being in Canada." *Economics & Human Biology* 5 (2): 204–28.

Davenport, Romola J. 2020. “Urbanization and Mortality in Britain, c. 180050.” *The Economic History Review* 73 (2): 455–85.

Drevenstedt, Greg L., Eileen M. Crimmins, Sarinnapha Vasunilashorn, and Caleb E. Finch. 2008. “The Rise and Fall of Excess Male Infant Mortality.” *Proceedings of the National Academy of Sciences* 105 (13): 5016–21.

Easterlin, Richard A. 1999. “How Beneficent Is the Market? A Look at the Modern History of Mortality.” *European Review of Economic History* 3 (3): 257–94.

Engels, Frederick. 1892. *The Condition of the Working-Class in England in 1844*. London: Swan Sonnenchein & Co.

Engerman, Stanley L. 1997. “The Standard of Living Debate in International Perspective: Measures and Indicators.” In *Health and Welfare During Industrialization*, 17–46. University of Chicago Press.

Grech, Victor. 2020. “The Sex Ratio at Birth Aspects.” *Early Human Development* 140 (January): 104857.

Griffin, Emma. 2018. “Diets, Hunger and Living Standards During the British Industrial Revolution.” *Past and Present* 239 (1): 71–111.

Haines, Michael R. 1979. “The Use of Model Life Tables to Estimate Mortality for the United States in the Late Nineteenth Century.” *Demography* 16 (2): 289–312.

———. 2001. “The Urban Mortality Transition in the United States, 1800-1940.” In *Annales de Démographie Historique*, 33–64. 1. Belin.

———. 2006. “Vital Statistics.” In *Historical Statistics of the United States*, Fourth, A: Population:381–90. New York: Cambridge Univ Press.

Hollingshaus, Mike, Rebecca Utz, Ryan Schacht, and Ken R. Smith. 2019. “Sex Ratios and Life Tables: Historical Demography of the Age at Which Women Outnumber Men in Seven Countries, 18502016.” *Historical Methods: A Journal of Quantitative and Interdisciplinary History* 52 (4): 244–53.

James, William H., and Victor Grech. 2017. “A Review of the Established and Suspected Causes of Variations in Human Sex Ratio at Birth.” *Early Human Development* 109: 50–56.

Kearns, Gerry. 1988. “The Urban Penalty and the Population History of England.” In *Society, Health and Population During the Demographic Transition*, 213–36. Umeå Universitet.; Demografiska Databasen No. 4. Stockholm: Almqvist & Wiksell.

Klasen, Stephan. 1994. “‘Missing Women’ Reconsidered.” *World Development* 22 (7): 1061–71.

Klasen, Stephan, and Claudia Wink. 2002. “A Turning Point in Gender Bias in Mortality? An Update on the Number of Missing Women.” *Population and Development Review* 28 (2): 285–312.

Komlos, John. 1998. “Shrinking in a Growing Economy? The Mystery of Physical Stature During the Industrial Revolution.” *The Journal of Economic History* 58 (3): 779–802.

Lee, Kwang-Sun. 2007. “Infant Mortality Decline in the Late 19th and Early 20th Centuries: The Role of Market Milk.” *Perspectives in Biology and Medicine* 50 (4): 585–602.

Maconochie, Noreen, and Eve Roman. 1997. “Sex Ratios: Are There Natural Variations Within the Human Population?” *BJOG: An International Journal of Obstetrics & Gynaecology* 104 (9): 1050–3.

McKeown, Thomas. 1976. “The Modern Rise of Population.”

Mitchell, Brian. 1998. *International Historical Statistics: Europe 1750-1993.* Springer.

Pelletier, François, Jacques Légaré, and Robert Bourbeau. 1997. “Mortality in Quebec During the Nineteenth Century: From the State to the Cities.” *Population Studies* 51 (1): 93–103.

Pozzi, Lucia, and Diego Ramiro Fariñas. 2015. “Infant and Child Mortality in the Past.” In *Annales de Démographie Historique*, 55–75. 1. Belin.

Preston, Samuel H., and Etienne Van de Walle. 1978. “Urban French Mortality in the Nineteenth Century.” *Population Studies* 32 (2): 275–97.

Sanders, Nicholas J., and Charles Stoecker. 2015. “Where Have All the Young Men Gone? Using Sex Ratios to Measure Fetal Death Rates.” *Journal of Health Economics* 41 (May): 30–45.

Steckel, Richard. 2002. “A History of the Standard of Living in the United States.” *EH. Net Encyclopedia* 22.

Wadhera, Surinder, Jill Strachan, Statistics Canada, and Canadian Centre for Health Information. 1993. *Selected Infant Mortality and Related Statistics, Canada, 1921-1990.* Statistics Canada, Canada Centre for Health Information.

Woods, Robert I., Patricia A. Watterson, and John H. Woodward. 1988. “The Causes of Rapid Infant Mortality Decline in England and Wales, 1861–1921 Part I.” *Population Studies* 42 (3): 343–66.

8 Appendix

8.1 Age Heaping in the US Census

Throughout the paper, our sex-ratio measures cover the age groups under-two and under-five in order to compensate for patterns of widespread male-biased age heaping at age one in North American census data, as wells as to reduce spurious variation in sex-ratio values. Conceptually, our focus is on the infant sex ratio, with a female-biased ratio reflecting the female mortality advantage in deleterious conditions of maternal and infant health.[60] However, in practice, attention to broader age groups is more informative for two main reasons. First and most important, using the under-two sex ratio serves to compensate for male-biased age heaping at age one, which is a problem to varying degrees in census data (see below). Second, aggregation generally tends to reduce the influence of data errors and of random variation in observed sex ratios. Given the age-structure of infant and child mortality, with death-probabilities falling off by age two, observed differences in sex ratios across large populations of children are primarily determined by sex differences in mortality in infancy – or at least that is the case if infant mortality is high enough and mortal sex-discrimination is rare enough.[61] The female biological mortality advantage is likely to be evident in child sex ratios with IMR values of 50 per thousand or more, but not with rates on the order of 10 per thousand (or less).[62] And biology's female mortality advantage can too easily be reversed by mortal misogyny (female infanticide and other extremes of sex discrimination) – in which case it is male-biased sex ratios that warrant attention, as evidence of "missing women" (Sen 1990, among many possible).[63] However, mortal misogyny is likely to generate a pattern of increasingly male-biased sex-ratios with childhood age. In that case, the under-five sex ratio is likely to appear male-biased relative to the under-two sex ratio, a point which further recommends attention to sex ratios for both the under-two and under-five age groups.

The under-two age group is the narrowest cohort for which we report sex-ratios, in order to deal with a widespread problem of male-biased age-heaping at age one in US census data. The male-biased

[60] As discussed in the text, the female mortality advantage affects both the sex ratio at birth and the sex ratio of infant survivors in deleterious conditions that cause high rates of fetal loss and infant mortality.

[61] For simplicity, we pose the primacy of infant over child mortality in sex-ratio patterns as a maintained hypothesis for this research, but we are guided in part by simulations with model life tables. Simulations illustrate the plausibility of our assumption (i.e. the key role of mortality in infancy relative to childhood), but life table models are not conclusive here, because they can vary widely in terms of the size and the age-structure of the female mortality advantage, with varying implications for sex-ratios patterns across ages and mortality regimes. Indeed, comparing two model populations, the one with greater infant mortality could have less female-biased sex-ratios, if it also had a sufficiently smaller female mortality advantage.

[62] Child sex ratios will not be informative indicators of infant and maternal health when infant mortality rates are on the order of 1% or less. To illustrate, consider Bell & Miller's (2003:53) life table for the US in 1990, with an IMR of 9 per 1000 and a female biological mortality advantage of 4/5: there is only a 0.2-%-point difference between the sex ratio at birth and the infant sex ratio (e.g. 105.5 and 105.3 boys per 100 girls; or 94.8 and 95.0 girls per 100 boys). So small a female-bias in the sex ratio is empirically negligible, if only because that size of year-to-year variation in the sex ratio at birth is common in US data for the later 20th century (Mathews & Hamilton 2005:10).

[63] By the late 20th century, with the spread of ultrasound, sex-selective abortion is another source of variation in infant sex ratios.

age-heaping renders the under-one sex ratio largely uninformative, with an artificial female-bias that is about equal and opposite to an artificial male-bias in the age-one sex ratio. Aggregation across the two age-groups serves to correct for those artificial biases, and to reveal sex ratio patterns of interest. For most census years, pinning down patterns of age-heaping would be prohibitively costly (either in terms of time and effort, or paying Ancestry.com). However, for 1860, we have access to machine-readable data at the level of the individual census enumerator, in connection to on-going research on literacy. Looking at results for the state of New York demonstrates the nature of male-biased age-heaping in that census year.

The *Population* volume of the 1860 US Census reports "population by age and sex" for "under 1" (u1) and "1 and under 5" (1to5) and for a series of 5-year and 10-year age-groups. For NY state, the published data give a value of 98.2 girls per 100 boys under the age of 1, distinctly more female than the 97.5 value for the age 1to5 cohort, and substantially more female than the expected sex ratio at birth (~95 girls per 100 boys). Taken at face value, the relative female-bias of the u1-sex ratio might suggest poor maternal and infant health circa 1860. However, digging into the census data reveals a problem of male-biased age-heaping of infants at age 1. Using the PUMS full count dataset, we can break out children's populations at one-year intervals, which reveals an anomalously male value of 96.1 for the ratio of girls to boys age 1, with the sex ratios for other years-of-age falling in a narrow range from 97.5 to 98.4 boys per hundred girls. In our view, the sex-ratio information in these data are obscured by the age-heaping at age one-year, which has a slight male bias. Some support for our view comes from the counts at infants at various months of age. There are just 4522 infants in the 11-month-old group and 7615 infants in the next smallest group, the seven-month olds (unsurprisingly, the numbers pile up at 6-months old, where we find 13,647 infants; the next largest group is the 3-month-olds, with 11,368 infants). And among 11-month olds, there are 102 girls per ever 100 boys, suggesting that relatively more males than females were subject to rounding up from 11-months to one-year, when their ages were enumerated. Pooling the infants and one-year-olds largely corrects for the effects of sex-biased age-heaping, revealing a more credible sex-ratio pattern, with the ratio of girls to boys under age-two being 97.2, with the under-5 category have a value of 98. Those sex-ratios are roughly typical of healthy populations of the mid-19th century (lower than we now see, having driven infant mortality down to less than 1% in OECD countries).

8.1.1 NY State, 1860: Infant and Young-child Sex Ratios

We have access to the full-count census data for New York at the level of individual enumeration district, which enables us to better identify the role of selective age-heaping in these data. We deem districts with more one-year-olds than infants to exhibit (of infants under-one into the one-year age-group). Within the age-heaping districts, ratio of girls to boys age 1 was a whopping

94.1 boys per 100 girls, which was substantially above the under-one value of 97.9.[64] Looking at the enumeration-district level of data points to the need to look at sex-ratio values across adjacent ages. To the extent that 11-month-old boys tended to be enumerated as one-year olds, the infant sex-ratio will be biased toward girls and the one-year sex ratio will be biased toward boys, with the opposing biases of similar magnitudes. But aggregating the under-one and age-one counts will eliminate that source of bias.

Table 2: Counts of boys and girls in the 1860 US census, New York.

	Age in Years						
	0	1	2	3	4	1to4	5
Male	51075	51757	55751	54923	54096	803091	51170
Female	50841	49738	54723	54042	52788	783546	49891
Ratio	99.5	96.1	98.2	98.4	97.6	97.6	97.5

8.2 Tables of Data

8.3 Infant Sex Ratios by Source: Published Census Volumes and PUMS

We take US census data from two sources: the published census volumes and the full-count Public Use Microdata Sample (PUMS). While the two sources are broadly concurrent, there are some years where they diverge. Note in Figures 13, 14 and 15 that the divergence is generally smaller for the ratio of girls to boys ages 0 to 4 than for the under-2 ratio. This is another reason to rely on ages 0 to 4 rather than only ages 0 and 1, beyond the age heaping discussed in Appendix 8.1.

8.4 IMR-SR Line Fit

Here we plot the lines which give the conjectured infant mortality rate for the 19th-century USA and Canada. We fit a log-linear relationship between infant mortality and the ratio of girls to boys ages 0 to 4.

[64] As a check, we restricted attention to enumeration districts with at least 70 infants (under-1), eliminating very small counts in which random variation in the under-1 sex ratio could dominate patterns of interest. Restricting attention to districts with at least 70 infants, within the age-heaping districts the ratio of girls to boys at age one was 93.7 while the under-one sex-ratio was 97.9. So we get the same basic result whether or not we restrict attention to districts with at least 70 infants.

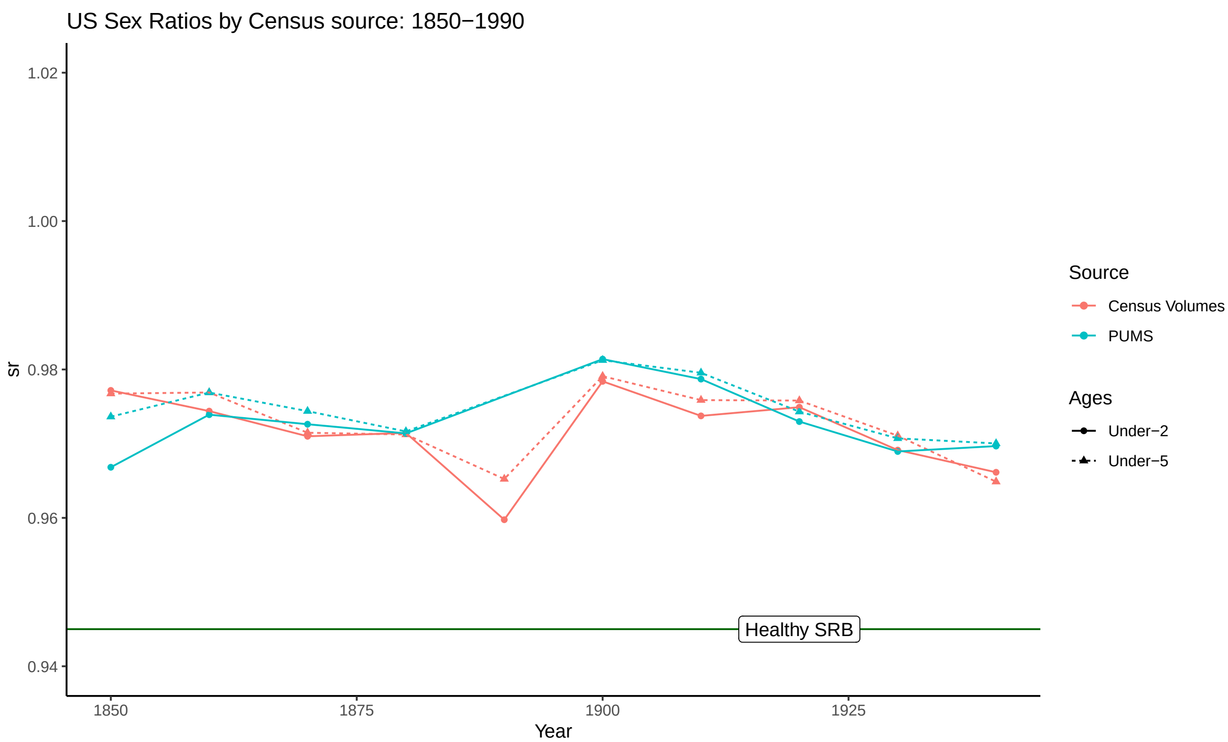

Figure 13: The ratio of girls to boys, ages 0 and 1: US 1850-1940. Source, the US Census: PUMs and published Census Volumes. The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls).

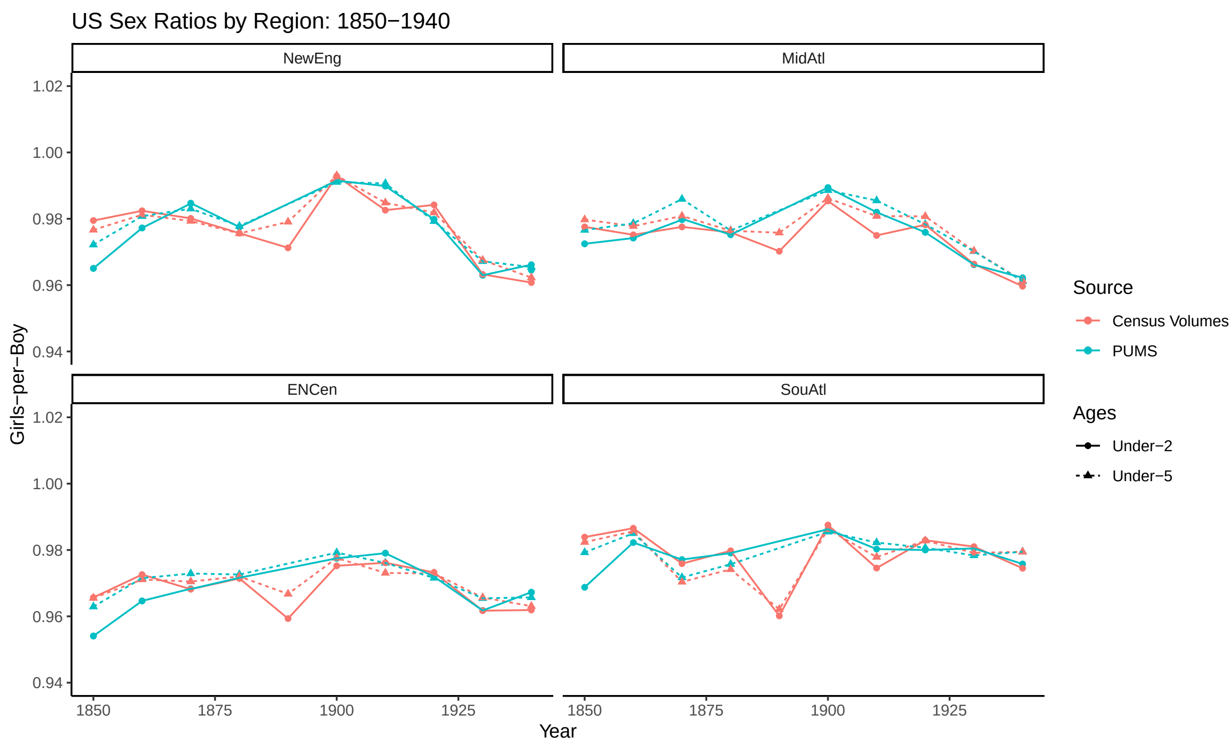

Figure 14: The ratio of girls to boys, ages 0 and 1: US regions 1850-1940. Source, the US Census: PUMs and published Census Volumes. The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls).

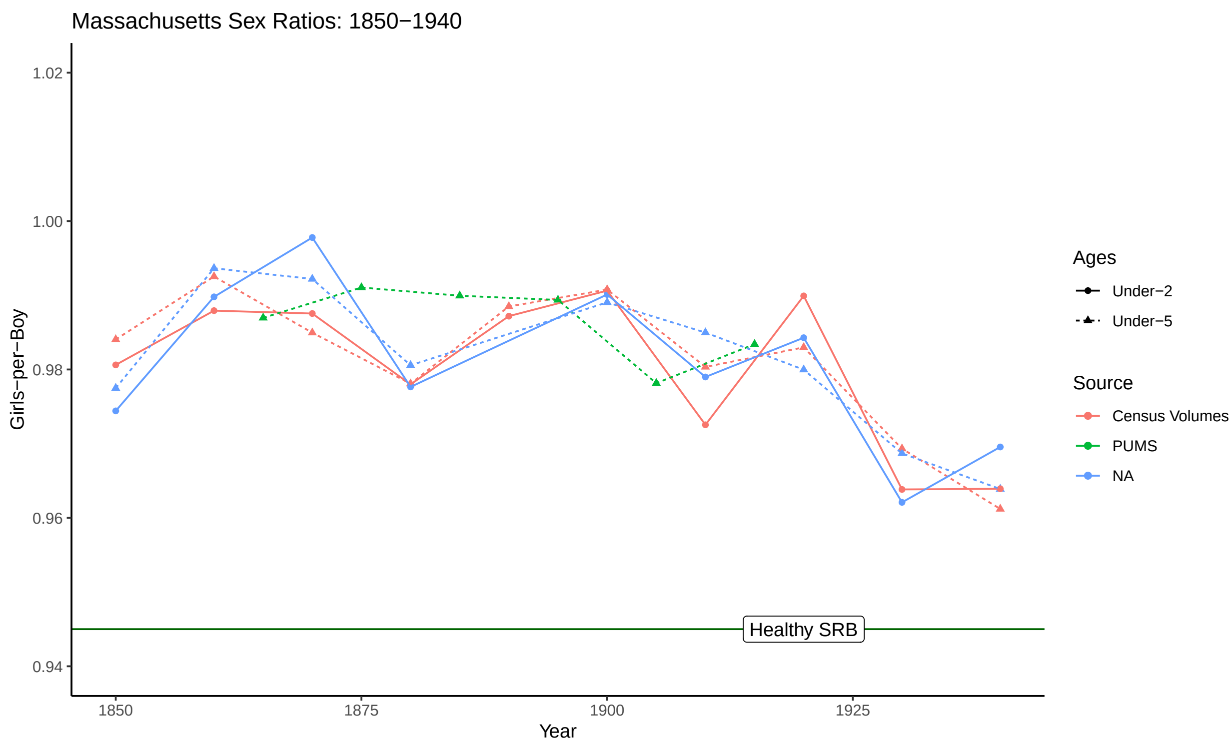

Figure 15: The ratio of girls to boys, ages 0 and 1 and ages 0 to 4: Massachusetts 1850-1940. Source, the US Census: PUMs and published Census Volumes. The green line represents a healthy sex ratio at birth of 94.5 girls per 100 boys (105.8 boys per 100 girls).

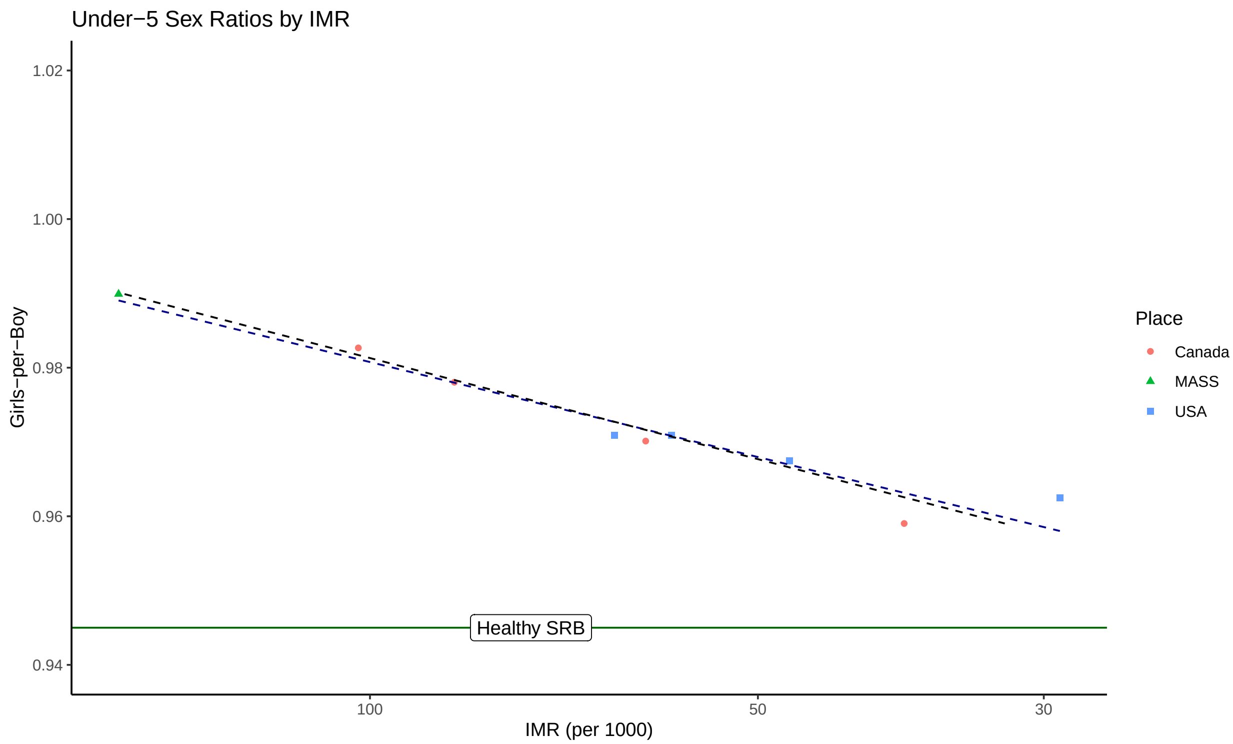

Figure 16: Ratio of girls to boys ages 0 to 4 by infant mortality: USA and Canada. Two fitted lines: