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EXPLORING THE VARIATIONS OF THE SEX RATIO AT BIRTH FROM AN HISTORICAL PERSPECTIVE

Francesco Scalone [1]
Dipartimento di Scienze Statistiche, Università di Bologna, Bologna, Italia
Rosella Rettaroli
Dipartimento di Scienze Statistiche, Università di Bologna, Bologna, Italia.

1. Introduction

The human sex ratio at birth is calculated by dividing the number of male births per 100 female births; an excess of males in almost all human populations has been registered (Cavalli-Sforza and Bodmer, 1971; Pressat, 1983; Sieff, 1990). The sex ratio at birth is also referred to as the secondary ratio in order to distinguish it from the primary sex ratio that takes into account the ratio at conception. In this paper, we only consider the secondary sex ratio.

In most Western developed countries with high-quality demographic statistics, the human birth sex ratio is generally around 105, whereas in some Asian countries, for example, India, China, South Korea, and Taiwan, the sex ratios show higher levels, revealing the effects of human interference and under-reporting of females (Gupta and Bhat, 1997; Dyson, 2012; Gu and Roy, 1995; Park and Cho, 1995; Zeng *et al.*, 1993).

In this paper, we do not consider variations in the sex ratio at birth due to the effects of human intervention, such as selective abortion and female infanticide, but we focus on non-deliberate or unwilling factors.

Do historical trends and short-term fluctuations of secondary sex ratios really exist? The study on the variations of sex ratio at birth is an active research field and the debate on this topic is still open. The main contributions come from several disciplines, involving not only historical and bio-demography, but also evolutionary biology, studies in human reproduction and life sciences.

First, Gini's studies on the sex ratio at birth are taken into account, summarizing his conclusions on historical trends and variations of secondary sex ratio. According to Gini, there was a universal excess of male neonates, while sex ratios at birth should be considered as an invariant bio-statistical parameter of mankind. In the last decades, several contributions have directly challenged Gini's conclusions by extensively exploring the historical trends and the geographic variations of

[1] Corresponding Author. E-mail: francesco.scalone@unibo.it

the sex ratio at birth. Even though the variations in the human sex ratio have not been completely explained and some leading scholars (Wilcox, 2010) are perplexed about future progress in this research field, we review the main determinants and theories from previous studies. Special attention is also paid to recent trends and the effects of environmental changes, pollution and climate.

2. The Sources for Historical Studies on Sex Ratios at Birth

Before reviewing previous studies on the historical tendencies and variations of the secondary sex ratio, it is necessary to highlight the most critical aspect related to the main sources of this kind of analysis. Since most studies on human sex ratios are of necessity observational, the analysis could be biased by data and registration problems. Therefore, some data quality issues could also arise when using micro and macro data on births (DelPanta and Rettaroli, 1994).

In the past, human sex ratios at birth were mainly explored by using civil registrations of births from official statistics or religious sources, such as the registers of baptisms. Other data could also come from registers of hospitals, clinics, or other birth institutions. In recent years, surveys on samples of women were also carried out in order to collect retrospective data and reconstruct birth histories.

It is necessary therefore to consider the possibility of misreporting, misrecording, or under-registering because of incomplete or inaccurate registrations of births or the survival of infants, both of which could bias the analysis of sex ratios. As Gini (1908) underlined, the overestimation of stillbirth registrations is one of the most critical issues and limitations that affected the quality of his data. In fact, a relevant problem regards the definitions of live birth, stillbirth, and perinatal death, which could change from one population to another. In addition, female births were often considerably under-recorded in historical demographic data, such as family or lineage genealogies and household or population registers. Unusual sex ratios at birth for some human populations could also be observed because of social or cultural gender driven preferences.

For example, China's birth sex ratios are evidently higher since they are biased by deliberate human interference, such as postnatal reproductive intervention and related under-enumeration (Zhao *et al.*, 2013). In addition, in some parts of Asia and North Africa, measures of sex ratios at birth could also be biased by selective abortions (Bongaarts and Guilmoto, 2015; Hesket and Xing, 2006).

3. The Human Sex Ratio at Birth in Gini's study

The stability of the sex ratio at birth is already known from the first studies of the earliest demographers in the seventeenth and the eighteenth centuries. In his book dated 1662, John Graunt carried out an exploration of the sex ratio at birth in the city of London, reporting a systematic excess of male neonates. In the following century, Sussmilch (1979) arrived at the same conclusion extending the study to other northern and central European countries. Taking into account many different countries around the world, other studies further confirmed the stability of the sex ratio at birth in the eighteenth and the nineteenth centuries.

Gini's work in "Il Sesso dal punto di vista statistico" (Gini, 1908) located his main research result in an interdisciplinary field at the crossroads of statistics, demography, and biology, detecting the sex ratio at birth in humans, animals, and vegetables. Taking into account the sex ratio in more selected groups of humans, such as stillbirths and twins, he also explored the effects of other sociodemographic factors, including age, profession, and polygamy, that distinguish the neonates' gender distribution, aiming to disentangle the influences of environment, natural selection, and individual variability. In Gini's view, the sex ratio's stability had relevant biological meaning and significant consequences on demographic phenomena and social structures, since the equilibrium between the two sexes in the adult ages play an extremely important role for the society and the economy. The combined effects of the sex ratio at birth, differences in mortality by sex, and migration levels from infant to adult ages determine the distribution of the population by age. In his view, an excess of unmarried women generally had a pernicious effect on populations and society. Only a constant excess of male neonates could balance the higher male mortality at subsequent ages, producing almost the same celibate and nubile amounts at the marital age.

According to Gini, since the sex ratio at birth is an expression of a casual process, its distribution has to be considered as an empirical determination of a random variable. From this pure statistical view, sex at birth is governed by the same probability laws ruling random phenomena. In his book (1908), Gini demonstrated how probability laws could be applied to study sex ratio variations at birth. He also showed how to calculate the probability of a female or a male birth in a given area using the data on the sex ratio at birth or, contrarily, to deduct the sex ratio at birth from the estimated probability of having a male neonate given a large number of observations. In these terms, Gini introduced and highlighted the problems related to confidence intervals of the sex ratios and the necessary amounts of observations to evaluate the significance of these proportions (Gini, 1908). He clearly explained that, without this kind of statistical approach, the main risk was to misunderstand and consider random fluctuations in sex ratios at birth as significant variations due to demographic and environmental determinants.

A world analysis of the historical variations of the sex ratios at birth covered a relevant part of Gini's "Il Sesso dal punto di vista statistico" (1908). In this book, he systematically collected new series on births by sex from various scholars and several national institutes of statistics, covering a lengthy period from the early decades of the seventeenth century to the beginning of the nineteenth, including populations living in towns and countries of Europe, Africa, America, Asia, and Oceania.

According to Gini's conclusions, the excess of male neonates with respect to female ones was universal since it was observed in every population and all countries, thereby undervaluing the possible effects of other environmental and social determinants. Given the limited variability across the different populations, the sex ratio at birth could be considered as a constant, while its fluctuations appear as random variations from the same identical level. As a logical conclusion, given a sufficiently large number of observations, the human sex ratio is a constant characteristic of mankind, without relevant historical variations and trends. However,

Gini did not interpret the higher proportion of males at birth as a clear effect of natural selection. In his view, a constant excess of male neonates represented a collective advantage for the whole species, although not for the single individual. He observed that the environment generally has such a weak effect on the variations of sex ratios at birth that it could play only a limited role in natural selection. Conversely, natural selection could reduce the effect of environmental constraints on sex ratios. At the same time, he warned that the higher proportion of male neonates could not be directly related to environmental characteristics since it could also be due to the indirect impact of higher embryonal mortality.

4. A Review of Recent Historical Studies on the Sex Ratio at Birth

As already mentioned above, Gini's study (1908) took into account almost all the best quality historical series of births that were published and available at his time. After Gini's study, interest in the subject waned, mainly because of the lack of reliable historical data. In the last decades, various studies have exploited new data sources and several findings have challenged Gini's conclusions. Therefore, a review of recent studies on human sex ratios at birth is presented focusing on some of the main points that Corrado Gini already highlighted.

Some historical trends and fluctuations of sex ratios will be firstly observed and commented. Afterwards, a review of the explanations given in the main scientific literature will be summarized, focusing on the possible determinants of the phenomenon as previously explored by Gini. So natural, genetic and socio/demographic factors will be firstly taken into account and then exogenous factors such as the effects of nutritional crises and environmental stressors will be considered.

4.1. Historical Trends of Sex Ratios during the Demographic Transition

Recently, some interesting findings derived from studies on Northern European countries, where long series of birth by sex are available because of their early system of statistical registrations. Considering Sweden from 1751 to 1950, the secondary sex ratios progressively increased, as they did in Finland, Norway, and Iceland in almost the same period. A previous study suggested that this secular increase is probably related to the improving socioeconomic conditions (Fellman and Eriksson, 2011). Intrauterine mortality played a central role in these trends. It was evident that stillbirth rates were higher among male neonates and progressively reduced as socio-economic levels improved. As a consequence, a decline in fetal mortality at the same time affected the secondary sex ratios. Nonetheless, it seems that secondary sex ratios are related to differences in the primary sex ratio at conception and sex-specific in-utero mortality. The intrauterine survival of the embryo is determined by embryo viability and the immunological interactions between embryo and mother. The secondary sex ratio could therefore be inversely related to the frequency of prenatal losses. However, this hypothesis is only weakly supported by the available data. No universally consistent results were found on the associations between sex ratios and stillbirths (Chahnazarian, 1988).

To further explain the variations in the secondary sex ratio levels during the demographic transition, one should also take into account the effects due to changing reproductive behavior. The long-term fertility decline firstly modified the distribution of births by birth order and the parental ages, therefore affecting the secondary sex ratio trends. Indeed, maternal age, paternal age, and birth order are the three demographic factors that could affect the variations of the sex ratio at birth. Older fathers have a tendency to produce fewer sons than younger fathers, whereas maternal age has probably little or no effect on the sex ratios at birth (Chahnazarian, 1988). In an analysis that took into account birth order, the effect of parental age diminished and the proportion of male births decreased as the number of prior births increased (Chahnazarian, 1988; James, 1987; Sieff, 1990).

Significant improvements in living standards, nutritional levels and socio-economic conditions could probably have played some role in reducing intra-uterine mortality and stillbirth rates. So it was also supposed that, in the period before the demographic transition, secondary sex ratios could vary among different status-based subgroups. However, it is possible that this relation could be due more to paternal age or birth order effects (Chahnazarian, 1988). Nutritional standards and severe malnutrition affected maternal and fetal health during pregnancy, playing a relevant role in short-term fluctuations of secondary sex ratios and long-term tendencies as well. It is possible that, in cases of maternal malnutrition during pregnancy, selective intrauterine mortality could eliminate the frailer male fetuses, favoring females. Even if there is a lack of reliable data before the demographic transition, a number of studies made an attempt to assess the effects of severe famines on the sex ratio at birth.

A previous study demonstrated that maternal nutrition in Bangladesh impacted the risk of miscarriage (Pebley *et al.*, 1985). A second case-controlled study was not able to replicate those findings (Stein and Kline, 1991). Another study showed that during China's 1958-1961 famine and the post-famine period, probabilities of female neonates increased (Song, 2012), whereas a subsequent analysis based on recent fertility surveys did not confirm those results (Zhao *et al.*, 2013). Other studies have not found any significant effects of severe food deprivation during the great Finnish famine of 1866-1868 and the Dutch hunger winter of 1944-1945 on birth sex ratio (Stein and Kline, 1991; Stein *et al.*, 2004). It is difficult to evaluate these controversial findings. Since maternal nutritional status at the time of conception might play a role (R. J. William, 1992; Andersson and Bergstrom, 1998), this type of study needs precise temporal information on maternal exposure to famine.

4.2. The Increase of Sex Ratios during the World Wars

An increase in the male proportion among births was observed in the twentieth century, during and immediately after wars. In fact, during the two World Wars, several European populations experienced an increase in sex ratios (James, 1987; Ulizzi and Zonta, 1995). Evident peaks in secondary sex ratios were observed during World Wars I and II in Germany (Bromen and Jockel, 1997; Graffelman

and Hoekstra, 2000), whereas in Finland (Vartiainen, Kartovaara, and Tuomisto, 1999), and in the Netherlands, these peaks only occurred during World War II since it remained neutral in World War I (Bromen and Jockel, 1997; van den Broek, 1997).

Even though recent studies have taken into account the effects of warfare on the secondary sex ratio, the reason for the increase in the proportion of males among births during wartime is still not well understood. According to a recent hypothesis, in countries where wars have been prolonged and severe, increases of male births are probably due to the tremendous stress experienced by the women. The explanation for this phenomenon depends on a more complete understanding of the endocrinological modulation of primary sex determination and sex-specic embryonic survival (James, 2009). According to a proposed theory, the sex of the offspring depends on the hormonal status of the parents (James, 1987, 1996) with high levels of estrogen and testosterone increasing the probability of a male birth and high levels of gonadotrophin decreasing it. Therefore, hormonal variations at the moment of conception should be related to a higher propensity for one sex at birth.

4.3. Contemporary Declining Trends in Industrialized Countries

After World War II, the human secondary sex ratio declined in some, but not all, developed countries (Moller, 1996; Parazzini *et al.*, 1998; James, 2000; Jongbloet *et al.*, 2001). Significant reductions in secondary sex ratios and a declining proportion of male neonates were reported in some countries, like Canada (Allan *et al.*, 1997) the United States (Marcus *et al.*, 1998), Denmark (Moller, 1996), Holland (van der Pal-de Bruin *et al.*, 1997), Germany (van den Broek, 1997), England and Wales (Manning *et al.*, 1997). The reasons for this long-term decrease remain unclear and are currently the subject of an ongoing debate.

However, not all countries have experienced a decline in sex ratios at birth. In Australia, the secondary sex ratio has remained stable (Lancaster and Day, 1998), while in Ireland the proportion of male neonates to females has increased in almost the same periods (Moynihan and Breathnach, 1999). The size of these changes in the sex ratios is very limited. Nevertheless, these small variations can have a statistical significance because of the large size of the studied populations (Allan et al., 1997). Parazzini *et al.* (1997) took into account the secondary sex ratios in Italy from 1926 to 1995, finding no evident trends.

One of the explanations for this phenomenon takes into account the possible effects due to nutritional habits. Women attending an English antenatal clinic were interviewed on their usual diet before conception, and a relationship was found between the secondary sex ratio and the preconception diet of the mothers. This association was explained as a causal link and suggested that the secular decline in the sex ratio in industrialized countries may also be due to slimming diets of young women (Mathews *et al.*, 2008). Gibson and Mace (2003) recently showed that a better nutritional status of nonpregnant women in Ethiopia could explain an increase in the proportion of males among live births. However, further analysis on a larger sample did not replicate these findings (Stein *et al.*, 2003).

Ecological factors could also play a role in the declining sex ratios at birth that have been observed in some populations in the last decades. A previous study suggested that a reduced male proportion at birth could be due to exposures to chemicals, such as pollutants from incinerators, pesticides, alcohol, lead, and other hazardous substances in the workplace (Fellman and Eriksson, 2011; Sieff, 1990). After the Seveso incident of 1976 in Italy, high concentrations of dioxins were associated with fewer males born (Mocarelli *et al.*, 1996).

It has also been proposed that feminizing chemicals could affect the male development in several vertebrate species, causing a decline in the human sex ratio and sperm count (Fellman and Eriksson, 2011). The decline in secondary sex ratios could also be related to clomiphene citrate, a drug that has powerful estrogenic and anti-estrogenic properties (Jarrell, 2002). Since 1965, clomiphene has been used to induce ovulation in the treatment of infertility and has had some effects on the sex ratio at birth in the subsequent decades (Vartiainen *et al.*, 1999). Although it is unclear how clomiphene citrate affects the sex ratio, its estrogenic and anti-estrogenic properties probably interfere on the estrogen receptors of the mother.

Various studies also took into account possible causes related to the climate change of the last decades, assessing the effects of temperatures on secondary sex ratios (Fukuda *et al.*, 2014). During the period from 1946 to 1995 in Germany, an excess of male births was related to two warm months preceding conception (Lerchl, 1999). It was also reported that the secondary sex ratio in certain populations could also be affected by month of birth, but the size of these seasonal variations was considered very small (James, 1987; Lerchl, 1999; Nonaka *et al.*, 1998, 1999).

However, measuring the effects of temperature on the birth sex ratio could be complex as contrasting and concurring mechanisms are active before and after conception. Temperature could affect primary sex determination by the variable fertilization success of X- and Y-bearing sperm (McLachlan and Storey, 2003). In mammals, ambient temperature affects the steroid concentrations of ovarian follicles (Wolfenson *et al.*, 2000; DeRensis and Scaramuzzi, 2003). Stressful environmental conditions could also impair sperm motility, potentially promoting a female-biased birth sex ratio (Fukuda *et al.*, 1996; Gomendio *et al.*, 2006). In addition, the relation between temperature and the secondary sex ratio could be due to selective fetal mortality since a sex ratio bias at birth toward females could be related to a higher mortality of more vulnerable male fetuses (Catalano *et al.*, 2005).

5. New Theoretical Perspectives

From the first studies on sex ratios at birth of the earliest demographers, the universal excess of male births and the stability of the ratio were clearly deducted. The Gini's work definitely gave a scientific base to these findings by adopting a modern statistical approach. He basically undervalued many of the social, geographical and environmental determinants that were supposed in the previous studies. In the last decades, further contributions from different disciplines partially confirmed the Gini's conclusions, since no clear effects of socio-economic

conditions and nutritional levels were found.

It is difficult to assess the effect of socioeconomic status on the secondary sex ratio, since parental status has to be measured around the time of conception and not some years before or after conception. A study on an elite sample of billionaires in the US showed that social status differences could emerge only when the measures of social status at different times are taken into account (Schnettler, 2013). Another critical aspect concerns the selection problem. The undernourished population in rural or pre-industrial societies could experience a serious reduction in fertility affecting the observed sex ratios at birth. During the Dutch Hunger Winter of 1944-1945 and China's 1958-1961 famine, a significant decrease in fertility was observed (Stein *et al.*, 2003; Zhao *et al.*, 2013). Severe malnutrition may also lead to the cessation of ovulation, loss of libido, and reduced sperm production, reducing fecundity (Dribe and Scalone, 2010).

By undervaluing the importance of the environment in sex ratio variations, Gini strongly limited the role that secondary sex ratio could play in the natural selection and in the human evolution. However, a new theoretical paradigm on this topic reopened the debate among evolutionary biologists and demographers, bringing Gini at the center of the stage again.

Based on an evolutionary perspective, Trivers and Willard (1973) proposed that the sex ratio at birth should be related to maternal condition. Also referred to as the adaptive sex ratio adjustment hypothesis, the offspring sex ratio of mothers in poor condition will be biased toward females. Therefore, when the maternal condition deteriorates, mothers tend to produce a lower ratio of males to females (Trivers and Willard, 1973), and this adjustment could occur both before and after the birth. The evolutionary explanation for this adjustment is based on the extra effort required to raise a male relative over a female one Trivers and Willard (1973). As Zhao *et al.* (2013) well explained, because the reproductive success of male offspring tends to be more variable and resource-sensitive than that of female offspring (Song, 2012), natural selection should favor parental ability to adjust the sex ratio of offspring produced according to parental ability to invest (Trivers and Willard, 1973).

In this theoretical framework, many factors associated with the variations of the sex ratio could have an adaptive value. Major famines provide opportunities for assessing this hypothesis since they generally cause a deterioration in living conditions. The physiological mechanisms of this adaptive selection are still unknown (Williams, 1979; Brown and Silk, 2002), but this sex ratio adjustment (alteration of the male-to-female ratio at birth in response to exogenous environmental changes) has been demonstrated in animal models (Huck *et al.*, 1988; Meikle and Thornton, 1995; Greeff and Ferguson, 1999; Kruuk *et al.*, 1999). However, recent studies on human populations have provided mixed results (Keller *et al.*, 2001; Lazarus, 2002; Gibson and Mace, 2003; Stein *et al.*, 2004; Cronk, 2007). Trivers and Willard (1973) also proposed that in the human population maternal condition could impact the secondary sex ratio, and this effect could be measured by using socioeconomic status. However, no studies have been carried out to indicate which of several indicators of socioeconomic status could better approximate the maternal condition at conception and during pregnancy.

It appears that the hypothesis of Trivers and Willard (1973) found more evidences and proofs only studying the sex ratios of not human species, confirming the Gini's (1908) observation that only the secondary ratio of the simplest species were more affected by the environmental factors. Further studies on the effects of socio-economic differences and severe malnutrition on human population could provide clearer and more definitive answers.

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Summary

Variations in sex ratios at birth is still an active research field and several studies in the last decades have focused on this topic. In this article, studies on the main determinant of long- and short-term trends are briefly reviewed, taking into account findings and results from different kinds of disciplines. In his early studies, Corrado Gini concluded that the human sex ratio at birth was universally stable, without significant fluctuations across time and space. However, in the last decades several authors have directly challenged these conclusions. Therefore, after summarizing the results of Ginis research on the historical trends of the sex ratio at birth, a brief review focuses on the analyses of contemporary trends. The main determinants of the variations of the sex ratio at birth in time and space mentioned in the literature and the corresponding theoretical explanations are summarized. Special attention is paid to the recent studies on the impact of the environment, pollution and climate on the levels of sex ratio at birth.

Keywords: Corrado Gini; sex ratio at birth; bio-demography; historical demography