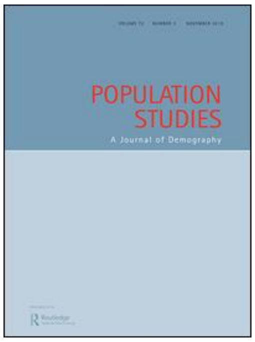

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Research Note

On the estimation of female births missing due to prenatal sex selection

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This research note is prompted by a paper by Kashyap (Is prenatal sex selection associated with lower female child mortality? Population Studies 73(1): 57–78). Kashyap's paper, which provides 40 original estimates of missing female births, relies on an alternative definition of missing female births, leading to estimates of about half the magnitude of other estimates. There appears, therefore, a real need to take stock of the concept of missing female births widely used by statisticians around the world for assessing the demographic consequences of prenatal sex selection. This research note starts with a brief review of the history of the concept and the difference between Amartya Sen's original method and the alternative method found elsewhere to compute missing female births. We then put forward three different arguments (deterministic and probabilistic approaches, and consistency analysis) in support of the original computation procedure based on the number of observed male births and the expected sex ratio at birth.

Keywords: gender; missing births; estimation; Amartya Sen; prenatal sex selection

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Introduction

Over the last 30 years, there has been a growing acknowledgment of the dramatic effect of sex discrimination on population sex ratios. This recognition is closely linked to the pioneer endeavour by Amartya Sen (1990) to put a figure to these 'missing women', using a simple counterfactual method still used today. The extent of these sex imbalances has led to a closer examination of their mechanisms and consequences, leading in particular to the emergence of new estimates of 'missing female births' (MiFB), 'missing children', 'missing births', and 'missing brides'.

This research note is prompted by a publication by Kashyap (2019) in this journal. Her paper refers to MiFB and offers 40 original estimates of their numbers in ten countries and for four periods. Kashyap's study relies, however, on an alternative definition of missing female births, leading to MiFB estimates of about half the magnitude of other estimates, as we will illustrate further. After exchanges with the author about estimation procedures, we realized there was a real need to take stock of the concept of MiFB, as it is widely used by statisticians around the world for assessing and monitoring the demographic consequences of prenatal sex selection.

This research note starts with a brief review of the history and development of the concept of MiFB and the way it has been calculated over the years. The next section presents both Sen's original method and an alternative method used in some papers to compute MiFB. It is followed by a longer section in which we put forward three different arguments in support of the original computation procedure. The note ends with a short summary of our findings.

History and use of the concept

Demographers started to provide evidence of unusually high levels of mortality among females in some areas about 50 years ago. El-Badry (1969) introduced the notion of excess mortality among females while reporting on 'a particular pattern of mortality in Ceylon, India and Pakistan where, contrary to general experience, female mortality is higher than that of the males'. Tabutin (1978) also described cases of excess mortality among females in nineteenth-century Europe. In the following decade, additional local studies, notably from South Asia, showed the extent of contemporary sex imbalances in infant and child mortality and linked these to systematic sex discrimination (D'Souza and Chen 1980; Miller 1984; Harriss 1989). This work led to the first efforts by Sen to estimate the number of missing females in different countries. A study by Drèze and Sen (1990, p. 52) estimated the number of missing women throughout the world in 1986 at 105 million. During the next decade, demographers and economists such as Coale (1991) and Klasen (1994) improved on the initial method by providing better estimates of the number of women expected in the absence of sex discrimination and excess mortality among females.

Meanwhile, anthropologists and subsequently demographers had also documented the emergence of skewed sex ratios at birth (SRB) (Jeffery et al. 1984; Hull 1990). It became necessary to distinguish prenatal from postnatal discrimination, the former being closely linked to sex-selective abortions while the latter represents excess mortality among girls. The sex imbalances at birth observed in countries such as China, India, and South Korea led in turn to the development of the notion of missing female births (or 'missing girls'). More recently, the excess of males among young adults in countries that have experienced sex imbalances at birth in the recent past has caused a mounting marriage squeeze and authors have now pointed to the large number of missing brides (Ahlawat 2009; Kaur 2013). In what follows, we will focus on defining and estimating the missing female births caused by prenatal sex selection.

The definition of MiFB

Before embarking on the technical discussion, let us detail the various demographic and probabilistic notations used in this note:

OB = Number of observed total births (OFB and OMB for observed female and male births),

EB = Number of expected total births (EFB and EMB for expected female and male births) according to Sen's original method,

OSRB = Observed sex ratio at birth = OMB / OFB,

ESRB = Expected (biological) sex ratio at birth, and

MiFB = Number of missing female births according to Sen's original method.

Note that OFB = OB/(1 + OSRB) and OMB = OB × OSRB/(1 + OSRB). Later on in the paper, the superscript * refers to variables computed with the alternative method (e.g. EFB* and MiFB*).

The concept of missing births arises from a simple counterfactual question: how many female births would we expect in the absence of deliberate prenatal sex selection? The number missing is computed as the difference between the expected and the observed numbers of female births:

$$\mathrm{MiFB} = \mathrm{EFB} - \mathrm{OFB}. \tag{1}$$

Measuring missing female births using Sen's approach.

The method used here is derived from the original estimate by Sen in his work on missing women and depends on the computation of the expected figure for females. Drèze and Sen (1990, p. 52) computed, for instance, the expected female population as the number of women in a country if its sex ratio were the same as in a region devoid of sex discrimination, given its actual male population. Applied to births (rather than to populations), and using a biological SRB (rather than a population sex ratio), the expected number of female births represents a counterfactual derived from the observed number of male births and the expected biological SRB as shown in this formula:

$$\mathrm{EFB} = \mathrm{OMB}/\mathrm{ESRB}. \tag{2}$$

It follows that:

$$\mathrm{MiFB} = \mathrm{OMB}/\mathrm{ESRB} - \mathrm{OFB}. \tag{3}$$

Measuring missing female births using the alternative approach

Sen's method for computing MiFB has often been applied in the literature without any discussion or presentation. This may explain why other authors have also applied their own methods without describing the procedure followed. Kashyap (2019, p. 63), however, spells out an alternative method of estimation in which the biological SRB is applied to the *total* number of births rather than to the number of *male* births. This alternative procedure can be summarized thus:

$$\mathrm{EFB}^* = \mathrm{OB}/(1+\mathrm{ESRB}). \quad (4)$$

It follows that:

$$\begin{aligned}\mathrm{MiFB}^* &= \mathrm{EFB}^* - \mathrm{OFB}\\ &= \mathrm{OB}/(1+\mathrm{ESRB}) - \mathrm{OFB}\\ &= \mathrm{OB}/(1+\mathrm{ESRB})\\ &\quad - \mathrm{OB}/(1+\mathrm{OSRB}). \quad (5)\end{aligned}$$

The implications of the selection of one of these two methods are considerable, as they lead to estimates varying by up to 100 per cent (see also Equation (9) later). For instance, when computing the range of sex imbalances at birth in 2010–15, Kashyap finds 1.79 million missing female births in China and 1.54 million in India. Using the same data but Sen's original method, Bongaarts and Guilmoto (2015) instead found 3.48 and 3.00 million missing female births in China and India, respectively. These estimates are around 95 per cent larger than Kashyap's and the same disparity in estimates is found for all 40 estimates in her paper. Other well-cited papers using the same alternative method (Arnold et al. 2002; Jha et al. 2006) have provided figures leading to identical shortfalls in the numbers of estimated missing female births.

Three approaches to understanding the logic and the implications of the computational methods

The variations between methods used stem from the assumption of the reduction in total births implicit in Sen's method but not in the alternative method. The extent of these variations calls for a systematic examination of their respective merits. In this section, we confront the validity of the original and alternative methods through three different approaches. We start with a deterministic approach to estimating missing female births. We then introduce a probabilistic modelling of sex-selective abortions to be compared with missing female births. We finally propose a consistency analysis of these estimates in relation to other estimates of missing females.

A deterministic approach

We examine here the logic behind Sen's original method (hereafter referred to simply as the 'original method') and the alternative estimation method. We show in particular that the alternative method implies the presence of excess male births that cannot be accounted for by the process of birth reduction intrinsic to sex-selective behaviour—an unexpected outcome that users of this estimation method have not discussed.

It is assumed that sex imbalances at birth reflect the net effect of prenatal sex selection affecting primarily female births via sex-selective abortions. In the original method, for a given number of observed *male* births (OMB), the expected number of female births (EFB), in the absence of sex selection, is found by applying the expected sex ratio at birth (ESRB) to OMB as shown previously in Equation (2). The number of missing female births, MiFB, is then given by the difference between the expected and observed numbers of female births in Equation (3). The total number of expected births would then be given by the sum of the observed number of male births and expected number of female births, that is,

$$\mathrm{EB} = \mathrm{OMB} + \mathrm{EFB} = \mathrm{OMB} + \mathrm{OMB}/\mathrm{ESRB}. \quad (6)$$

This formulation assumes that the number of female births has been reduced through prenatal sex selection. In contrast, the number of male births has not been affected by prenatal selection and serves therefore as a benchmark to derive the expected number of female births.

In the alternative method summarized by Equation (4), the number of missing female births, MiFB*, is given in Equation (5) used by Kashyap (2019). Here, the ESRB is applied to the *total* number of observed births (OB) to compute EFB* and the observed births are redistributed by sex according to the ESRB*. Contrary to the original method, the total number of expected births remains unaffected by prenatal sex selection.

A further implication of this alternative formula, ignored in the papers using this method, is that the expected number of male births is smaller than that observed (i.e. there was an overcount of male births which now gets corrected). This approach may be suitable in contexts of *misreporting of sex at birth* (e.g. in cases where female births are reported as male), as this formula keeps the total number of births as fixed and simply redistributes the births by sex. However, this does not account for *births that* *are missing* due to sex selection and the resulting reduction in observed births.

Using the definition of OSRB, the original and alternative formulas for missing female births can be rewritten, respectively, as:

$$\begin{aligned}\mathrm{MiFB} &= \{[\mathrm{OB} \times \mathrm{OSRB}/(1+\mathrm{OSRB})]/\mathrm{ESRB}\} \\ &\quad - \mathrm{OB}/(1+\mathrm{OSRB}) \\ &= \mathrm{OB} \\ &\quad \times (\mathrm{OSRB} - \mathrm{ESRB})/[(1+\mathrm{OSRB}) \times \mathrm{ESRB}],\end{aligned} \tag{7}$$

and

$$\begin{aligned}\mathrm{MiFB}^* &= [\mathrm{OB}/(1+\mathrm{ESRB})] - [\mathrm{OB}/(1+\mathrm{OSRB})] \\ &= \{\mathrm{OB} \times (\mathrm{OSRB} - \mathrm{ESRB})/[(1+\mathrm{OSRB}) \\ &\quad \times \mathrm{ESRB}]\} \times [\mathrm{ESRB}/(1+\mathrm{ESRB})].\end{aligned} \tag{8}$$

It can finally be shown that:

$$\begin{aligned}\mathrm{MiFB}^* &= \mathrm{MiFB} \times \mathrm{ESRB}/(1+\mathrm{ESRB}) \\ &\approx \mathrm{MiFB} \times 0.51,\end{aligned} \tag{9}$$

where ESRB is in the 1.04–1.06 range.

Thus, MiFB* is nearly half the magnitude of MiFB. This is seen in the comparison of estimates from Bongaarts and Guilmoto (2015) and from Kashyap (2019) presented in the previous section. This may also be illustrated by a simple, hypothetical case study in which we observe 110 male births vs. 100 female births in spite of a biological SRB set at 1.00. The original method leads to an estimate of MiFB = 10. In contrast, the alternative method results in MiFB* = 5. The gap between these estimates stems from the unexplained five excess male births (110 observed against 105 expected) derived from the alternative procedure.

A probabilistic view

In this section, we offer an internal demonstration of the consistency of the original method with a probabilistic model of sex-selective behaviour, showing that the estimated number of abortions is equivalent to the number of missing female births derived from Sen's method.

In a heterogeneous population (Alcalde-Unzu et al. 2020), couples practising sex selection represent only a fraction, θ, of all couples who give birth. These couples, when sonless after *(n – 1)* previous births, will eliminate female births at parity *n* until they get a boy. This may lead them to several selective abortions before the birth of a son. Based on this assumption, we derive the number of female foetuses aborted at a given birth order. Note that the demonstration adopts a longitudinal approach by following the birth histories of a cohort of women and that it is strictly based on their births, not on pregnancies. The model also considers the sex ratios at conception and at birth as equivalent.

Additional probabilistic notations are introduced here, with the subscript *n* referring to parity:

π = Expected proportion of male births at all parities = ESRB /(1 + ESRB),

p_n = Observed proportion of male births at parity n = OSRB / (1 + OSRB),

θ_n = Proportion of couples who will abort female pregnancies at parity n until having a male birth (i.e. proportion of couples at parity n who will practise sex selection), and

FA_n = Number of female pregnancies aborted at parity n.

Since we assume that the sex selection only happens at the last parity, *n*, MiFB in this section also stands for the missing female births at parity *n*. Similarly, $\mathrm{FA}_n = \mathrm{FA}$. The expected and observed SRBs at parity *n* can be expressed as:

$$\mathrm{ESRB} = \pi/(1-\pi), \tag{10}$$

and

$$\mathrm{OSRB}_n = p_n/(1-p_n). \tag{11}$$

Then Equation (3) can be written in terms of the proportion of male births:

$$\mathrm{MiFB} = \mathrm{OB}_n \times (p_n - \pi)/\pi, \tag{12}$$

and in terms of sex ratios:

$$\begin{aligned}\mathrm{MiFB} &= \mathrm{OB}_n \\ &\quad \times (\mathrm{OSRB}_n - \mathrm{ESRB})/[(1+\mathrm{OSRB}_n) \times \mathrm{ESRB}].\end{aligned} \tag{13}$$

The observed proportion of male births at parity *n* can be decomposed into three parts:

$$\begin{aligned}p_n &= [1-(1-\pi)^{n-1}] \times \pi + (1-\pi)^{n-1} \\ &\quad \times (1-\theta_n) \times \pi + (1-\pi)^{n-1} \times \theta_n,\end{aligned} \tag{14}$$

The proportion who have at least one son among their first *(n – 1)* births and hence do not practise sex selection is shown by $[1 - (1-\pi)^{n-1}]$, while $(1-\pi)^{n-1} \times (1-\theta_n)$ is the proportion with no son among their first *(n – 1)* births and who do not practise sex selection. These first two groups do not practise sex selection and hence have an average proportion of π male births. The third part $(1-\pi)^{n-1} \times \theta_n$ represents sex-selecting couples who will therefore all have a son at parity *n*.

It follows from Equation (14) that:

$$p_n = [\pi + (1-\pi)^n \times \theta_n]. \tag{15}$$

Substituting Equation (15) in Equation (11), we can express the observed SRB at parity *n* using θ_n:

$$\begin{aligned}\mathrm{OSRB}_n &= p_n/(1-p_n)\\ &= [\pi + (1-\pi)^n \times \theta_n]/[(1-\pi) - \theta_n \times (1-\pi)^n]\end{aligned} \tag{16}$$

The denominator in Equation (16) represents the decrease in total female births due to averted female births among couples practising sex selection. It follows that θ_n can be expressed in terms of proportions of male births as well as sex ratios:

$$\begin{aligned}\theta_n &= (p_n - \pi)/(1-\pi)^n\\ &= (1+\mathrm{ESRB})^{n-1}\\ &\quad \times (\mathrm{OSRB}_n - \mathrm{ESRB})/(1+\mathrm{OSRB}_n).\end{aligned} \tag{17}$$

We also know that the number of aborted female pregnancies (i.e. the number of pregnancies a woman has before conceiving a son at a given parity level) follows a geometric distribution with the probability of 'success' (i.e. probability of conceiving a son) at π and the mean of the distribution at $(1-\pi)/\pi$. The number of aborted female pregnancies can now be computed based on θ_n. We have:

$$\mathrm{FA} = \mathrm{OB}_n \times (1-\pi)^{n-1} \times \theta_n \times (1-\pi)/\pi, \tag{18}$$

where $\mathrm{OB}_n \times (1-\pi)^{n-1}$ is the number of couples with no son after $(n-1)$ births, θ_n is the propensity to practise sex selection, and (1−π)/π is the mean number of abortions per such couple. Using Equation (17) to substitute θ_n, we have:

$$\begin{aligned}\mathrm{FA} &= \mathrm{OB}_n \times (1-\pi)^{n-1}\\ &\quad \times [(p_n-\pi)/(1-\pi)^n] \times (1-\pi)/\pi\\ &= \mathrm{OB}_n \times (p_n-\pi)/\pi = \mathrm{MiFB}.\end{aligned} \tag{19}$$

QED

We can also confirm the same result using sex ratio notations in Equation (18):

$$\mathrm{FA} = [\mathrm{OB}_n/(1+\mathrm{ESRB})^{n-1}] \times \theta_n \times 1/\mathrm{ESRB}. \tag{20}$$

Replacing θ_n using Equation (17), we can achieve Equation (13). QED.

This demonstrates that Sen's original computation perfectly agrees with a probabilistic model of sex-selective behaviour. In contrast, the alternative method yields figures that do not agree with the estimated number of sex-selective abortions. A generalized model (not shown here) in which couples may practise sex selection irrespective of the sex of their previous births similarly yields the same correspondence with Sen's computation.

A consistency argument

We finally examine in this section how far the previous MiFB estimates tally with estimates of missing females in the population. Following Sen's method, the expected female population is computed by applying a 'normal' sex ratio, itself derived from the biological SRB and from the sex ratio of survival rates drawn from life tables or from non-discriminating populations. Consistency requires that as a product of both pre- and postnatal sex selection, the number of women missing is the sum of women missing at birth in the past and women missing later in life due to excess mortality among females. More precisely, the number of missing females at age *a* in a given cohort should be equal to the expected number of survivors among girls missing at birth in this cohort added to the excess deaths of females experienced by this cohort up to age *a*. This equality has already been confirmed by Bongaarts and Guilmoto (2015) in their estimation of the demographic consequences of pre- and postnatal sex selection on a global scale.

Let us now return to the previous illustration given earlier in this section, in which we have 110 male births and 100 female births, and a biological SRB of 1.00. Let us further assume no mortality at all in childhood, which means that 110 boys and 100 girls will reach age five. The expected sex ratio at age five should be 1.00 (equal to the expected SRB of 1.00) and the missing girls at age five would then number ten according to Sen's original method. This figure equals the sum of ten girls missing at birth and zero missing due to childhood mortality. In contrast, the alternative method would lead to a discrepancy. The sum of girls missing at birth (MiFB* = 5) and missing due to excess mortality (zero) falls short of the ten girls missing at age five. This gap is entirely due to the underestimation of girls missing at birth according to the alternative method. Further simulations with parameters closer to the real-life SRB and mortality values would lead to identical gaps between MiFB* and the number of missing females in the population.

In short, the alternative estimation method provides estimates of MiFB that conflict with estimates of the number of females missing later in life. To be consistent, the alternative method would require a change in the way missing females are computed (using the total population as a reference rather than the male population) and would generate an unlikely number of excess males in the population. Since sex selection is implemented through selective abortions and excess mortality of females, this excess once again appears illogical.

Discussion and concluding remarks

The method modelled on Sen's original computation of missing women remains the only one providing accurate and consistent estimates of the number of missing female births. We have first shown how it captures the demography of fertility reduction inherent in sex-biased abortions without generating any artificial excess male births. We have further shown how these results can be replicated with a probabilistic model of sex-selective female abortions, using parameters of sex-selective behaviour that are flexible enough to reproduce the sex imbalances at various birth orders observed across the world. We have finally shown that this method is the only one to coincide with estimates of females missing later in life and therefore ensures consistency with estimates of excess mortality among females.

It seems, therefore, impractical to use an alternative method, as it would lead to numerous demographic inconsistencies. The alternative method is based on a set of counterfactuals that entirely misses the process of birth reduction underlying sex-selective abortions. This method results in incorrect estimates of MiFB that seriously understate the impact of prenatal sex selection by a factor of almost two, a variability level unacceptable for any demographic measurement. The source of the confusion may be linked to the initial notion of missing women when a more neutral term such as 'gender gap' might have avoided some ambiguities.

Such miscalculations, however, have the potential to blur the seriousness of the issue. They run the risk of confusing journalists, observers, activists, and policymakers by generating inconsistency across estimation sources and potential incredulity among data commentators. With 45 million MiFB globally from 1970 to 2017 (Chao et al. 2019), this issue is obviously not just a matter of demographic correctness.

Notes and acknowledgements

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