

Gender Differences in Infant and Child Mortality: Estimation of Sex-Specific Mortality and an Assessment of Excess Female Deaths*

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1 Introduction

After birth, girls have biological advantages over boys with respect to survival for many causes of death. Under natural circumstances, the ratio of the male to female under-five mortality rate (U5MR, the probability of dying before age 5), is greater than one. However, deprivation of girls access to health care or proper nutrition could lead to distorted ratios of under-five mortality (E. J. Croll 2000). Current international monitoring initiatives call for disaggregation of under-five mortality rates by sex.

Recent assessments that synthesized data from various sources have been in agreement that a number of countries in southern Asia experience higher mortality for girls compared to boys from one to four years old (Sawyer 2012; Wang et al. 2012). However, findings on whether higher female than male mortality at ages 1-4 exists in scattered countries in other

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parts of the world, including northern Africa/western Asia, parts of sub-Saharan Africa, and Latin America, are inconsistent.

Unfortunately, monitoring of sex differences in mortality is challenging because of issues with data availability and quality. This is illustrated in Figure 1, which shows observations on the ratio of male to female U5MR in Jordan (denoted by SR5). The data, which come from a variety of surveys, censuses and vital registration, do not provide a coherent story on levels and trends in SR5. Smoothing or modeling techniques must be applied to arrive at estimates that can be used for international comparisons. Estimation methods should convey the uncertainty in the underlying data.

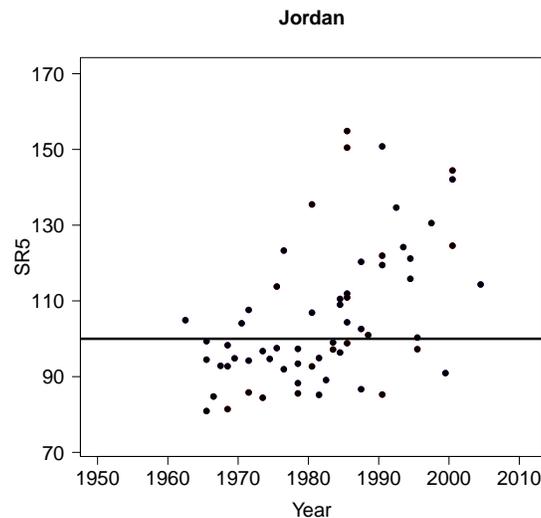


Figure 1: Illustration of SR5 observations for Jordan.

The monitoring of trends in sex differentials is further complicated by lack of a clear definition of how large we should expect girls' advantage to be. Boys and girls have different probabilities of death due to biological factors, and these differences vary between infancy and early childhood. If sex-disaggregated estimates are to be used for monitoring or advocacy purposes, it must be clearly explained to users (1) what the expected differences are, (2) when a given difference might indicate excessive disadvantage for one sex or the other, and (3) how to understand changes. The SR5 tends to vary with U5MR as shown in Figure 2. As under-five mortality decreases, the share of causes of death that more typically affect boys tends to increase and girls' advantage tend to increase as well. Given that girls are expected to have lower mortality under natural circumstances, it is possible for girls to have lower absolute mortality than boys but still be prevented from enjoying their full biological advantage due to some level of disadvantaging treatment. Some studies have used standards based on data from selected Western countries to assess female disadvantage (Hill and Upchurch 1995; Monden and Smits 2013) or calculate excess female deaths (World Bank 2011). Other studies (Sawyer 2012; United Nations 2011) have noted this difficulty but avoided the selection of a comparative reference level, highlighting only absolute excess of female mortality. Still others (Wang et al. 2012) have published estimates of sex-specific child mortality but refrained from

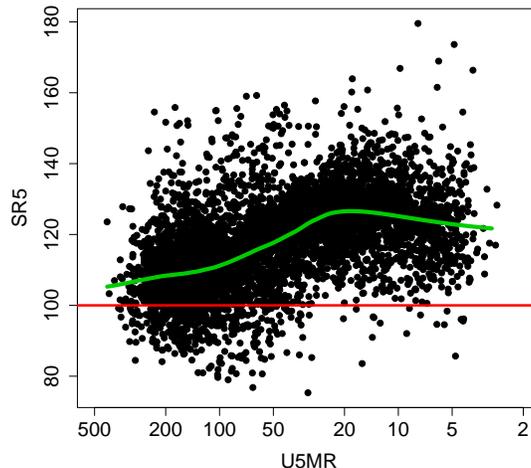


Figure 2: Illustration of the empirical relation between SR5 and U5MR. SR5 observations from all countries are plotted in black versus U5MR (on log-scale), a loess smoother is added in green.

analysis of sex differences.

We developed a new modeling approach to estimate levels and trends in sex ratios for infant, child and under-5 mortality for all countries (Alkema et al. 2013a; Alkema et al. 2013b). The approach takes into account data quality issues, includes an uncertainty assessment and that improves upon existing approaches by providing information on whether the estimated sex ratio is higher or lower than expected, based on an estimated global relations between mortality levels and sex ratios. The approach was used by the United Nations Inter-Agency Group for Child Mortality Estimates (UN IGME) to construct sex-specific mortality estimates (United Nations Inter-agency Group for Child Mortality Estimation 2013).

In this extended abstract, we describe the data and model used to construct the sex-specific estimates and identify countries with outlying sex ratios, and present illustrative results.

2 Data

The data used in this study are observed sex ratios since 1950 for infant, child and under-five mortality from vital registration systems (VR), sample registration/surveillance systems (SRS), surveys and censuses.

Data from VR/SRS were used to obtain sex ratios for age groups 0 and 1–4 through standard life table methods. Sex ratios for the age group 0–4 were not used to avoid using the same data twice.

For estimates from full birth histories collected in Demographic and Health Surveys, World Fertility Surveys and selected surveys from the Pan-Arab Programme on Family

Health (PAPFAM), sex ratios for infant mortality from full birth histories were calculated for periods of varying lengths, according to the method in Pedersen and Liu (2012). For sex ratios for ages 1-4, 5-year estimates were used. As for VR/SRS data, sex ratios for the age group 0-4 are not used to avoid using the same data twice.

For surveys and censuses in which only summary birth histories were collected, sex-specific indirect estimates of U5MR were calculated using the Brass method either from microdata or from published tabulations of children ever born and children living.

In cases where microdata or tabulations were not available, direct or indirect estimates were taken from published survey or census reports.

3 Estimating sex ratios

3.1 Overview and notation

Given differences in sex ratios for infants and children, we estimated the relation between mortality levels and sex ratios separately for both age groups (as opposed to directly estimating the relation between the U5MR and SR5).

For infants, we estimated a global relation between IMR and the sex ratio for infants (denoted by SR1) and used that relation to construct the expected SR1 for each country-year. These expected sex-ratios were multiplied by a second component, the country-specific multiplier for the infant sex ratio, that represents the relative advantage or disadvantage of girls to boys compared to other countries at similar mortality rates. This multiplier was modeled for each country by a time series model and estimated using the available data in the country. The country-specific levels that these multipliers fluctuate around were estimated using a Bayesian hierarchical model, allowing for countries with outlying levels.

The global relation between child mortality (CM) and its sex ratio (SR4) is estimated in a similar fashion. Finally, for each country-year, the expected level of SR5 is derived from the expected level of SR1 and SR4 (based on the estimates for IMR and CM).

In the model description, the sex ratios for infant, child and under-five mortality are denoted by $S_{a,c,t}$ for country c , year t for $a = 1, 4, 5$ respectively; index a refers to age groups $[0, 1)$, $[1, 5)$ and $[0, 5)$ respectively. The infant, child and under-five mortality rates are denoted by $Q_{a,c,t}$ for the corresponding age group and country-year. The j -th observed ratio of male to female mortality is denoted by $s_{a,j}$ in country $c[a, j]$, year $t[a, j]$ for $a = 1, 4, 5$.

3.2 Technical details for estimating SR1 and SR4

$S_{a,c,t}$ for $a = 1, 4$ is modeled as follows:

$$\begin{aligned} S_{a,c,t} &= W_{a,c,t} \cdot P_{a,c,t}, \\ W_{a,c,t} &= f^{(a)}(Q_{a,c,t}), \end{aligned}$$

where $f^{(a)}(\cdot)$ represents the relation between the level of mortality for both sexes combined and the expected sex ratio on a global level, and $P_{a,c,t}$ represents the relative advantage or disadvantage of girls to boys compared to other countries at similar mortality rates, as indicated by the data in the country.

The country multipliers $P_{a,c,t}$ are estimated with a time series model:

$$\begin{aligned}\log(P_{a,c,t}) &= \beta_{a,c} + \varepsilon_{a,c,t}, \\ \varepsilon_{a,c,t} &\sim N(\rho \cdot \varepsilon_{a,c,t-1}, \sigma_\varepsilon^2),\end{aligned}$$

where the multiplier fluctuates around country-specific level $\beta_{a,c}$. The fluctuations $\varepsilon_{a,c,t}$ are modeled with an autoregressive time series model of order 1.

Country-specific levels $\beta_{a,c}$ for $a = 1, 4$, representing the average level difference in $P_{a,c,t}$ across countries, are estimated using a hierarchical model (Lindley and Smith 1972; Gelman, Carlin, Stern, and Rubin 2004):

$$\beta_{a,c} \sim t_3(\mu = 0, \sigma^2 = \sigma_{a,\beta}^2, \nu = 3)T(\log(1.6)),$$

where a t -distribution with 3 degrees of freedom was chosen to allow for countries with outlying levels, and the truncation was imposed to exclude the possibility of extreme (and unrealistic) median country-specific levels (here the median levels are restricted to be smaller than 1.6).

Specification of global relation between mortality and sex ratios We use a flexible penalized B-splines regression model (Eilers and Marx 2010, 2011) to estimate the global relation between mortality and sex ratios, which is represented by function $f^{(a)}(\cdot)$, for age groups $a = 1, 4$. The function $f^{(a)}(q)$ for some value q for both-sexes mortality is specified as follows:

$$\log(f^{(a)}(q)) = \sum_{k=1}^{K_a} B_k^{(a)}(q) \alpha_k^{(a)}, \quad (1)$$

where $B_k^{(a)}(q)$ refers to the k -th B-spline evaluated at q and $\alpha_k^{(a)}$ to the k -th spline coefficients. B-splines are symmetric third-order polynomials that add up to one at any level of mortality. In this application, the splines are equally spaced on log-transformed Q and knots are set to be 0.3 apart. To avoid extreme extrapolations, splines are added up for $q < 0.005$ for $a = 1, 4$ and for q greater than the 95-th percentile of $Q_{a,c,t}$'s for country-years included in the data set. When fitting the splines model to observations, second-order differences in adjacent splines coefficients are penalized to guarantee smoothness of the resulting global norm. Spread out prior distributions are used for the splines model parameters. The expected sex ratio for country c , year t with mortality $Q_{a,c,t}$ is given by $W_{a,c,t} = f^{(a)}(Q_{a,c,t})$ for $a = 1, 4$ (where $Q_{a,c,t}$'s are rounded to 3 decimals to reduce the number of splines evaluations).

3.3 Derivation of SR5

SR5 for country c in year t , $S_{5,c,t}$, is derived from $S_{1,c,t}$ and $S_{4,c,t}$ through standard cohort equations (by calculating the sex-specific mortality rates for infants and children). The expected sex ratio $W_{5,c,t}$ for the country-year of interest is derived in a similar fashion, using $W_{1,c,t}$ and $W_{4,c,t}$ instead of $S_{1,c,t}$ and $S_{4,c,t}$. Finally, country multiplier $P_{5,c,t} = S_{5,c,t}/W_{5,c,t}$.

Contrary to age groups 0 and 1–4, there is no function that describes the global relation between mortality for both sexes combined and the expected sex ratio for ages 0–4 (because

the expected SR5 depends on the expected SR1 and SR4, which depend on the age-group specific mortality levels). To visualize the global relation between U5MR and the expected sex ratio, a Loess curve is fitted to all estimates of combinations $(Q_{5,c,t}, W_{5,c,t})$. The resulting relation will be denoted by $\tilde{f}^{(5)}(\cdot)$.

3.4 Data model

For most observations, observed sex ratios for age groups 1 and 4 are used. To avoid using data twice, observed under-5 sex ratios are not included if information on age groups 1 and 4 is included. There are two exceptions: (1) for observations from summary birth histories only sex ratios for age group 5 are used (unless these are missing while the sex ratios for the infant and children are available) and (2) for a small number of observations, information on sex ratios for infant mortality is missing. For these observations, information on the under-5 sex ratio is used instead.

For observations on age groups 1 and 4, the data model is given by

$$\log(s_{a,j}) \sim N(\log(S_{a,c[a,j],t[a,j]}), \sigma_{a,j}^2 + \omega_{a,x[a,j]}^2), \text{ for } a = 1, 4,$$

where $s_{a,j}$ is the j -th observed ratio of male to female mortality for age group a in country $c[a, j]$, year $t[a, j]$ for $a = 1, 4$, and $x[a, j]$ is the source type of that observation. The variance σ^2 is the sum of sampling variance $\sigma_{a,j}^2$ and non-sampling variance $\omega_{a,x[a,j]}^2$ (explained further below).

For observations from summary birth histories, and for a small number of observations where information on sex ratios for infant mortality is missing, the data model for observations from age group 5 is given by:

$$\log(s_{5,j}) \sim t(\mu = \log(S_{5,c[5,j],t[5,j]}), \sigma^2 = \sigma_{5,j}^2 + \omega_{5,x[5,j]}^2, \nu = \nu_5),$$

which is based on a t-distribution because additional analysis suggested that more outliers are present. The degrees of freedom ν_5 is assigned a spread out prior distribution.

Sampling variance is given for a large subset of DHS and MICS observations. For observations from vital registration systems, a Monte Carlo simulation was used to approximate the stochastic variances. For all other observations with missing standard errors, the standard error on the log-scale was set at 15%, approximately equal to the median standard error in the data set of non-VR observations. Non-sampling variance parameter $\omega_{a,x[a,j]}^2$ is estimated by source type and set to 0 for observations from VR/SRS.

3.5 Computing

A Markov Chain Monte Carlo (MCMC) algorithm was used to obtain samples from the posterior distribution of the parameters, implemented in the software JAGS (Plummer 2003). We used 24 parallel chains with a total of 150,000 iterations in each chain. Of these, the first 5,000 iterations in each chain were discarded as burn-in and after additional thinning, the resulting chains contained 8,640 samples each. Standard diagnostics checks (using trace plots and the Gelman and Rubin diagnostic (Gelman and Rubin 1992)) were used to check convergence.

Estimates of relevant quantities are given by the posterior medians while 90% credible intervals were constructed from the 5% and 95% percentiles of the posterior sample.

4 Results

4.1 Global relation between sex ratios and mortality levels

Figure 3 shows the estimated expected sex ratios (the $W_{a,c,t}$'s) based on the global relation between mortality levels and sex ratios for ages 0 and 1–4.

For age 0, the estimated expected sex ratio increases from 1.15 to 1.26 as mortality decreases from around 150 deaths per 1,000 births to around 20 deaths per 1,000 births. This increase is followed by a decrease in the estimated sex ratio from 1.26 to 1.20 as total IMR decreases from 20 to 5 deaths per 1,000 births.

For ages 1–4, estimated sex ratios are close to 1 for total mortality above 30 deaths per 1000 survivors up to age 1. The ratio increases as mortality decreases, the maximum of 1.21 is reached for mortality of 5 per 1,000.

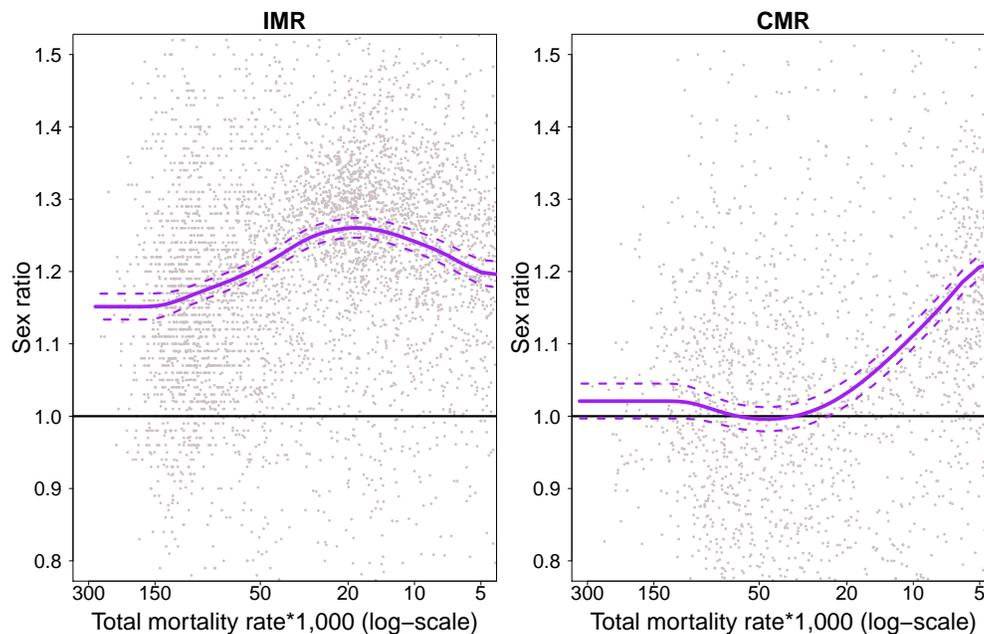


Figure 3: Estimated expected sex ratios ($W_{a,c,t}$) based on the global relation between sex ratios and mortality levels (purple, mortality level is plotted on the log-scale). Observed sex ratios (gray dots) are plotted against estimated mortality rates.

4.2 Illustrative country estimates

Figures 4 to 6 (at the end of this extended abstract) show estimates of sex ratios and country multipliers for Bangladesh, Burkina Faso, India, China, Jordan and Mongolia.

Burkina Faso is the only selected country for which multipliers are close to 1, indicating that observed sex ratios are in line with expected values (based on the global relation). For all other selected countries, the multipliers are significantly different from one for some period of time, indicating a relative advantage or disadvantage of girls to boys in the country of interest as compared to other countries at similar levels of mortality. Among the selected countries, Mongolia is the only country with multipliers greater than one, suggesting a greater than expected male survival disadvantage.

The estimated sex ratios are well above 1, indicating that infant and under-5 male mortality is almost 50% higher than female mortality for recent years.

A relative disadvantage for girls leads to estimated sex ratios that are smaller than one (and thus higher mortality for girls as compared to boys) for a subset of country-years, most notably for India for all age groups. However given the general biological advantage of girls over boys w.r.t. survival, a relative female disadvantage does not necessarily result in higher female mortality. For example, in Bangladesh, estimated sex ratios for the under-5 age group are greater than 1, indicating that male mortality is higher than female mortality, while country multipliers are below one and indicate a female disadvantage. Other examples include China and Jordan from around 1980. In these situations, the country multipliers help to pinpoint to country-periods with unusual sex ratios, that would go unnoticed when focusing solely on sex ratios that are smaller than 1.

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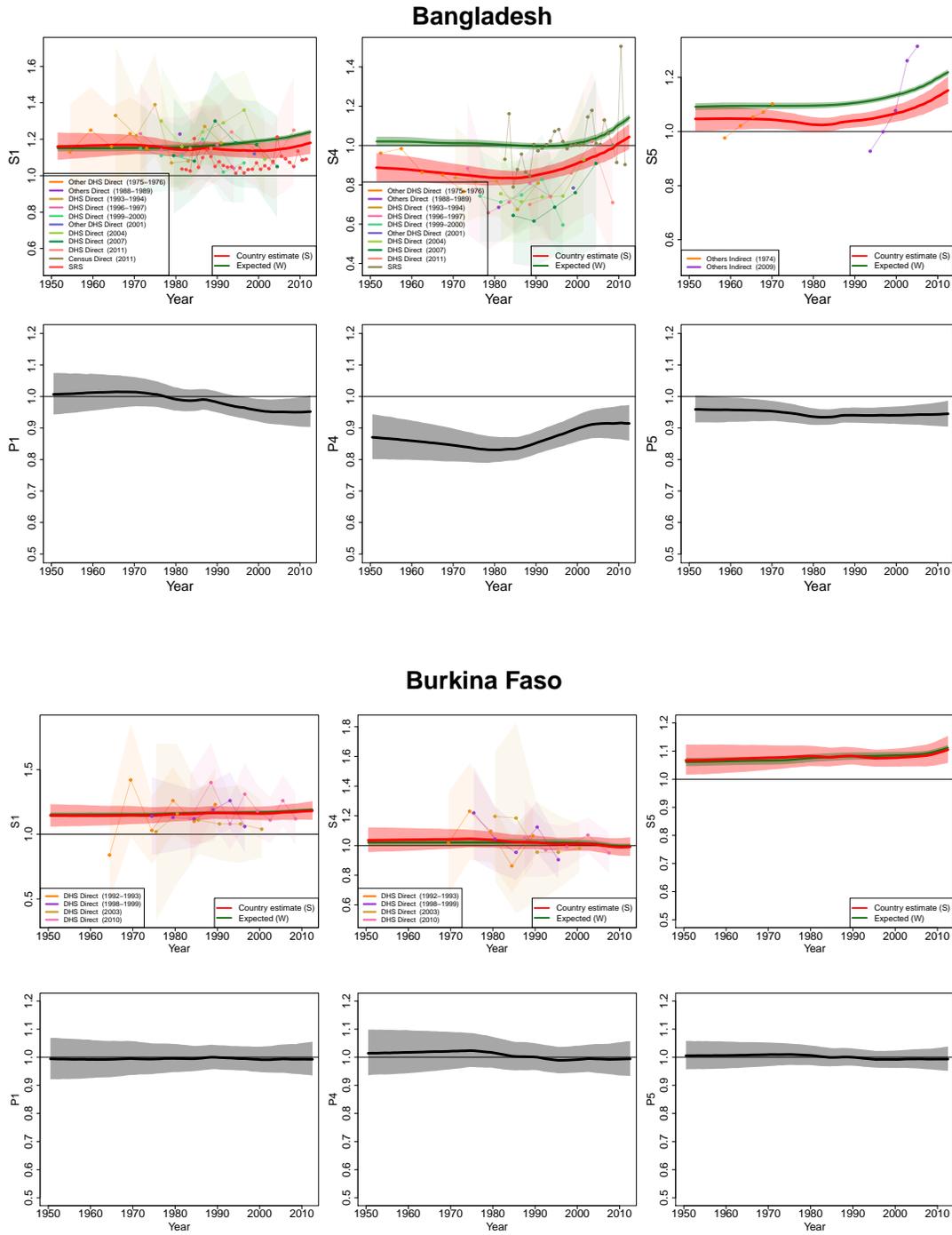
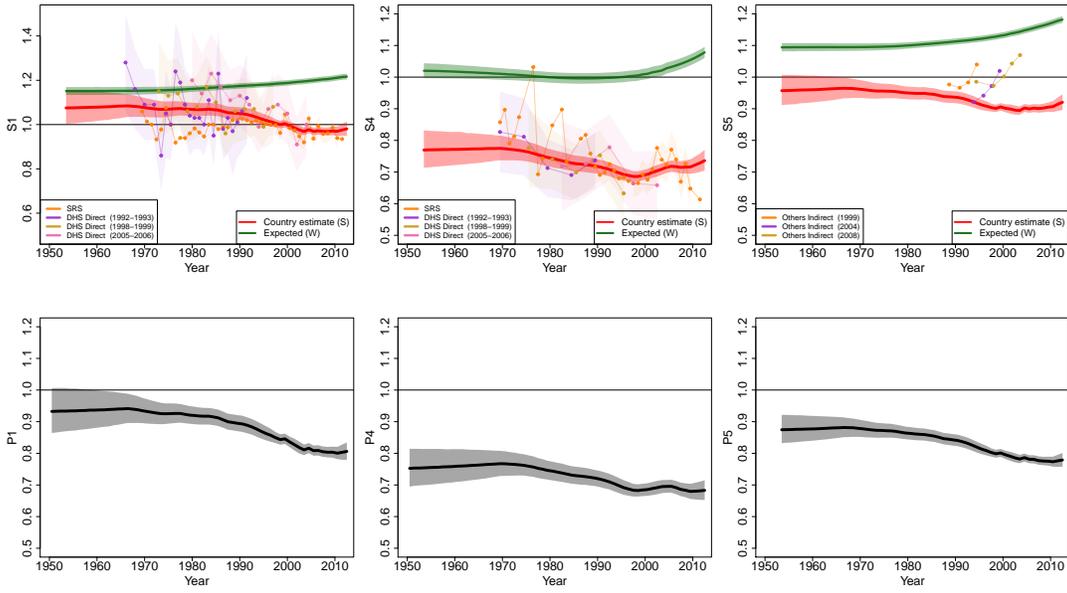


Figure 4: Estimates for Bangladesh and Burkina Faso. Top row: Estimated sex ratio $S_{a,c,t}$ for the three age groups (red) and expected sex ratio $W_{a,c,t}$ (green). Observations are displayed by dots, shaded areas around observations illustrate sampling errors (where available). Bottom row: Estimated country multipliers $P_{a,c,t}$, for the three age groups. Shaded areas around the estimates illustrate the 90% credible bounds.

India



China

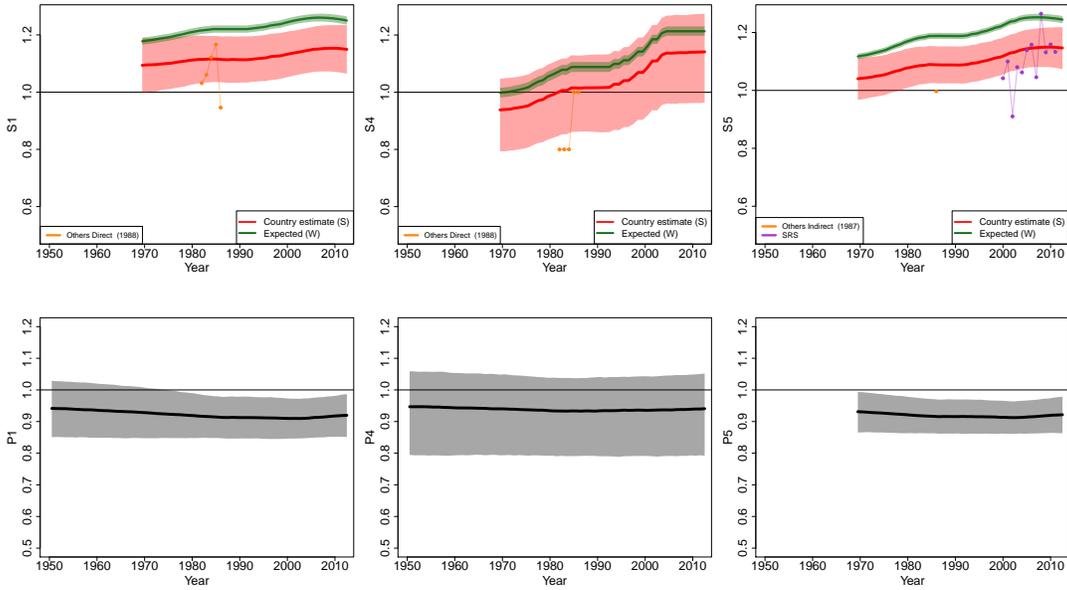


Figure 5: Estimates for India and China. Top row: Estimated sex ratio $S_{a,c,t}$ for the three age groups (red) and expected sex ratio $W_{a,c,t}$ (green). Observations are displayed by dots, shaded areas around observations illustrate sampling errors (where available). Bottom row: Estimated country multipliers $P_{a,c,t}$, for the three age groups. Shaded areas around the estimates illustrate the 90% credible bounds.

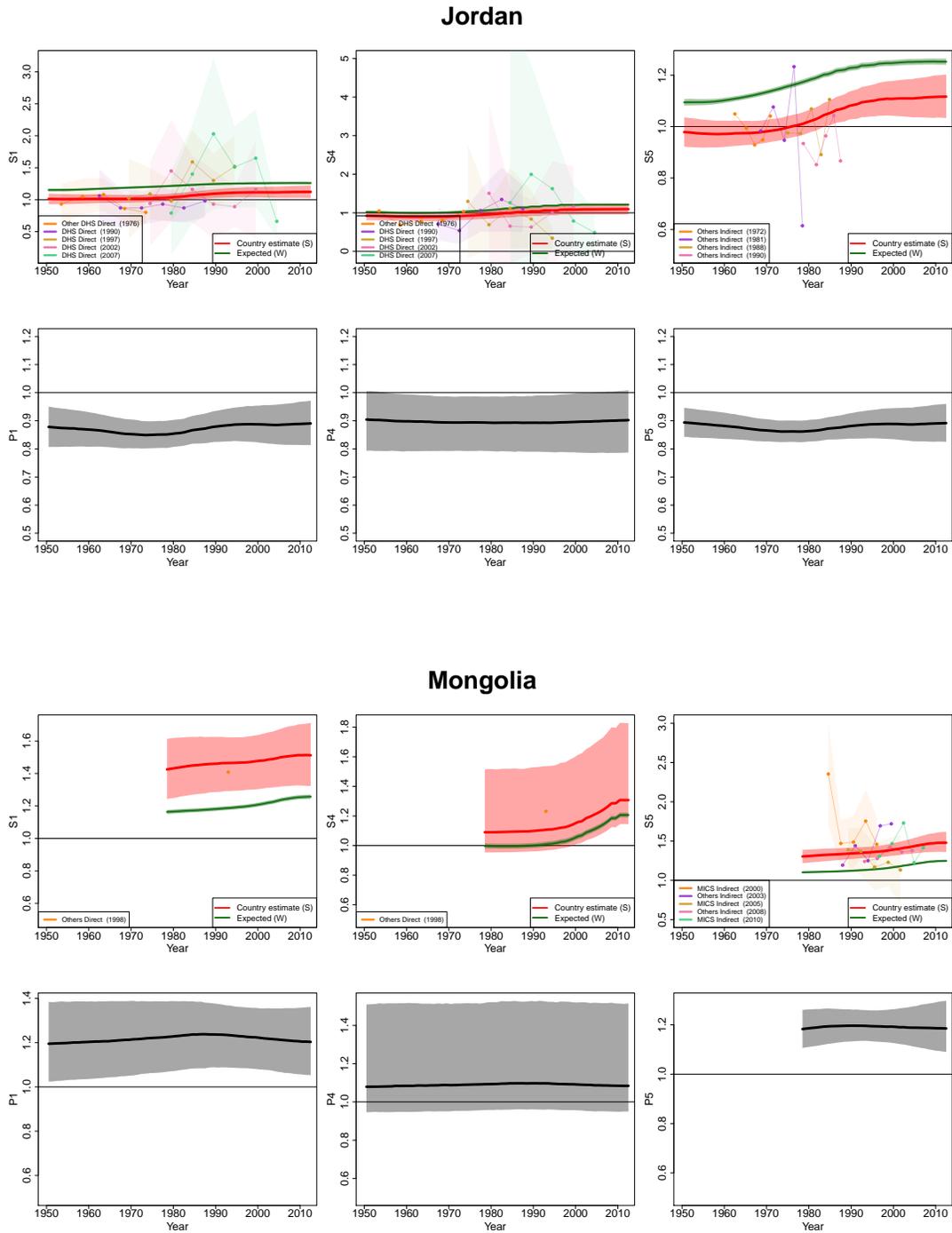


Figure 6: Estimates for Jordan and Mongolia. Top row: Estimated sex ratio $S_{a,c,t}$ for the three age groups (red) and expected sex ratio $W_{a,c,t}$ (green). Observations are displayed by dots, shaded areas around observations illustrate sampling errors (where available). Bottom row: Estimated country multipliers $P_{a,c,t}$, for the three age groups. Shaded areas around the estimates illustrate the 90% credible bounds.