Sex Ratio at Birth: Estimation and Projection using Bayesian Hierarchical Time Series Model

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Background

Current situation

- Under normal circumstance, the sex ratio at birth (SRB; i.e. number of male live births over number of female live births) varies between 1.04 and 1.07 (Chahnazarian, 1988).
- However, the observed SRB from countries like India and China have been well above the biological level for decades (Guilmoto, 2012; Goodkind, 2011).
- Characteristics for countries with SRB inflation (Guilmoto, 2012): 1) strong son preference; 2) widely available sex selection technology; 3) fertility squeeze, i.e. low total fertility rate (TFR, approximately the number of births per woman).
- So far, no assessment of SRBs for all countries over time has been carried out using all available data and reproducible estimation methods.

Objective

- To construct a database for SRB including data from vital registration and surveys;
- To estimate and project country-specific SRBs for 221 countries from 1990 (or the earliest year of data collection) to 2100, and assess the uncertainty in SRBs;
- To identify countries with outlying SRBs.

Data

Data Types	# obs.
Census	56
DHS	1,976
Other DHS	857
Others	148
VR	6,115
total	**9,152**

Table: **Database for modeling.** DHS: Demographic and Health Surveys; VR: Vital Registration.

- data are from 192 countries;
- 14,403 country-years of data;
- 67.9 country-years of data from each of the 221 countries estimated.

Method part 1: SRB model

We modeled the true SRB $R_{c,t}$ for country c (from region $r[c]$), year t as:

$$R_{c,t} = N_{r[c]} \cdot P_{c,t} + \alpha_{c,t}.$$

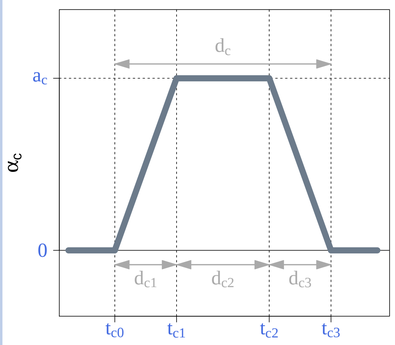
- N_r – the regional biological norm for SRB: estimated using data from country-years without potential prenatal discrimination, and assumed to be constant over time. We used independent non-informative priors to estimate N_r:

$$N_r \sim N(1, 1.1), \text{ for } r = 1, \ldots, R.$$

- $P_{c,t}$ – the divergence from N_r for the respective country-year under natural circumstances: modeled with an autoregressive time series model of order one (AR(1)):

$$\log(P_{c,t}) \sim N_{(0.9,1.1)}(\rho \cdot \log(P_{c,t-1}), \sigma^2_\epsilon).$$

- $\alpha_{c,t}$ – the upward adjustment factor for selected countries to capture inflated SRB levels that may be due to potential son preference and sex-selective abortion.



- $t_{c,0}$: starting year of SRB inflation period;
- $d_c (= d_{c,1} + d_{c,2} + d_{c,3})$: total length of the inflation period;
- $t_{c,3} (= t_{c,0} + d_c)$: ending year of inflation period;
- a_c: maximum value that $\alpha_{c,t}$ could reach.

A Bayesian hierarchical model (Gelman A. et al., 2004; Lindley and Smith, 1972) is used to model country-level parameters:

$$a_c \sim N_{(0,+\infty)}(\mu_a, \sigma^2_a), \text{ for selected } c$$
$$d_{c,g} \sim N_{(0,+\infty)}(\mu_{d_g}, \sigma^2_{d_g}), \text{ for } g = 1, 2, 3.$$

We used the fertility squeeze criterion (3) to inform the starting year of past or future upwards adjustments $t_{c,0}$. The year when TFR hits 2.5 is used for all countries except India, based on empirical evidence from other countries:

$$t_{c,0} \sim N_{(1970,2100)}(t_{c,tfr.target}, \sigma^2_{tfr.target}), \text{ all except India,}$$
$$t_{c,0} \sim U(1970, 2100), \text{ for India.}$$

Method part 2: Selection of Countries to Model SRB Inflation

Selection of countries with potential son preference that leads to inflated SRB:

- Observed SRB is suspected to be beyond biological norm as supported by literature; OR
- Desired sex ratio at birth > 120 and/or sex ratio of last birth > 130 (Bongaarts 2013); OR
- Outlying female under-5 mortality rate (Alkema et al. 2014).

Method part 3: Data Model

We take into account sampling and non-sampling variances in our data model as follows:

$$\log(r_i) \sim N(\log(R_{c[i],t[i]}), \sigma^2_i + \omega^2_{s[i]}).$$

- r_i: the i-th observed SRB input data;
- σ^2_i: the i-th sampling/stochastic variance (calculated);
- $\omega^2_{s[i]}$: the i-th non-sampling variance (to be estimated), where $s[i]$ refers to the source type s for the i-th SRB observation. For VR data, we assume their non-sampling variances are zero.

Computing We obtained posterior samples of all the model parameters and hyper parameters using a Markov chain Monte Carlo (MCMC) algorithm, implemented in open source softwares `R 3.0.2` (R Core Team, 2016) and `JAGS 4.0.1` (Just Another Gibbs Sampler) (Plummer, 2015).

Result 1: SRB Country Estimates

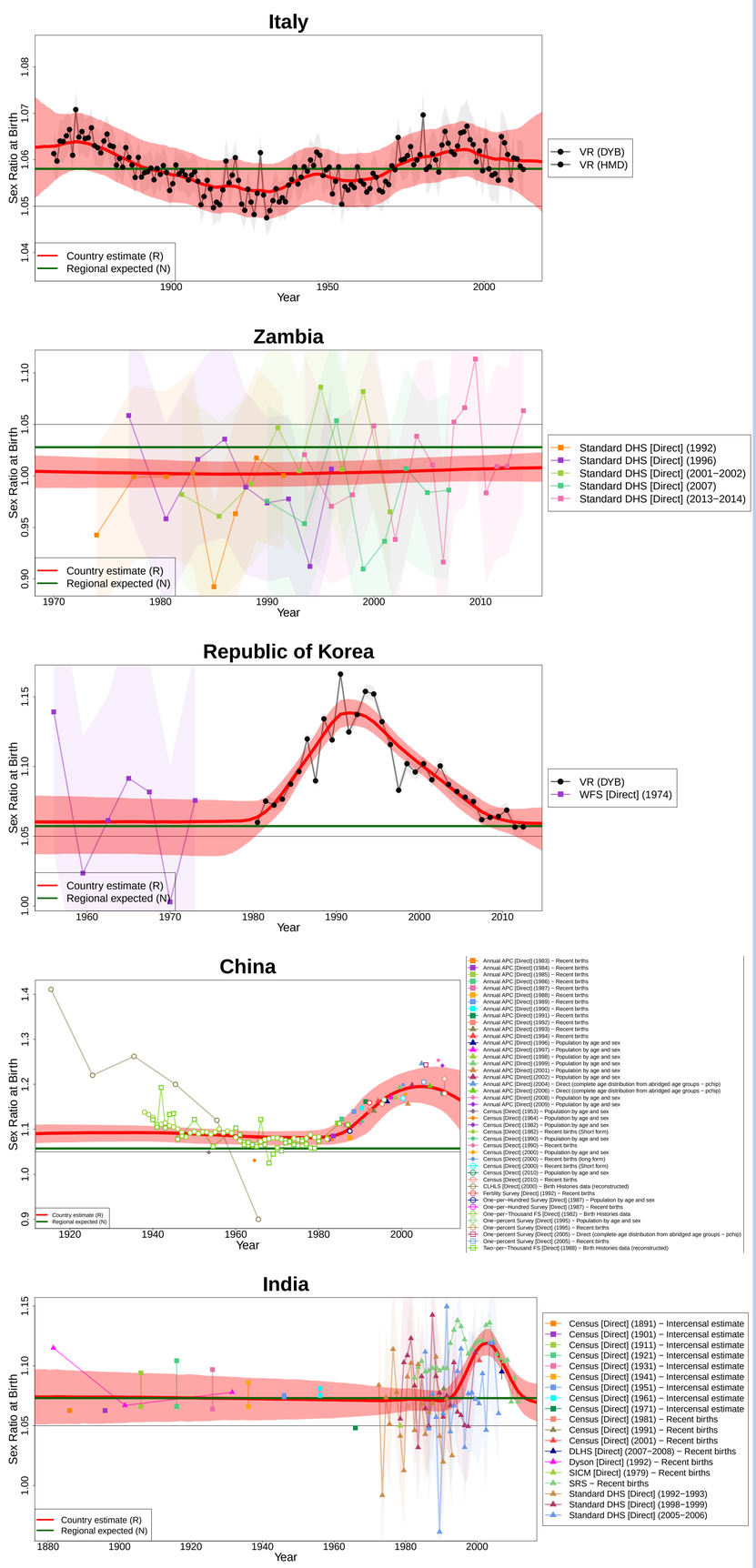


Figure: **SRB over time for Italy, Zambia, Republic of Korea, China, and India.**

Result 2: SRB Country Projections

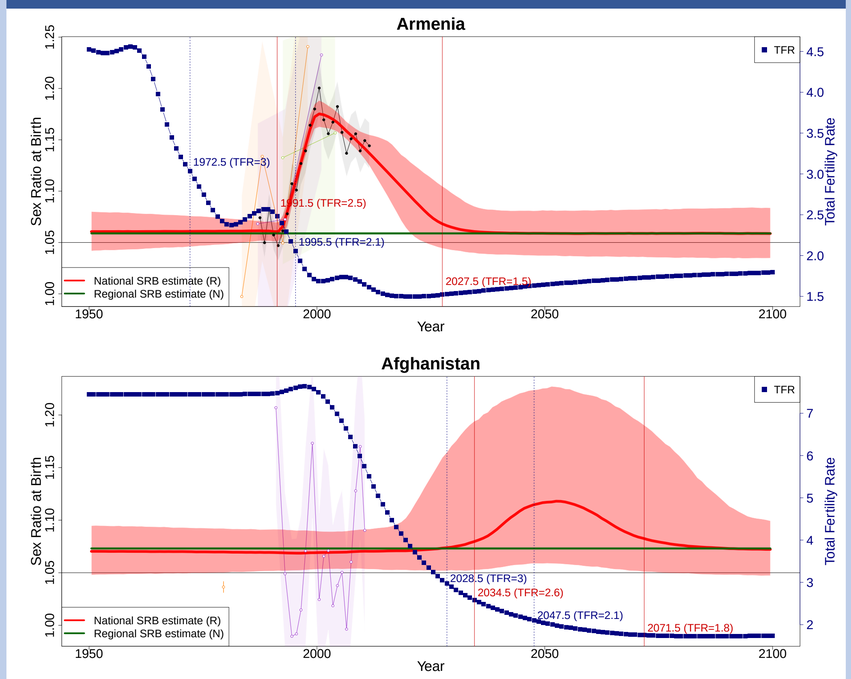


Figure: **SRB over time for Armenia, and Afghanistan.** Illustrations of projections for countries with ongoing and potential future SRB inflations, with TFR estimates and projections from the United Nations (2015 version).

Result 3: Countries with Outlying SRB

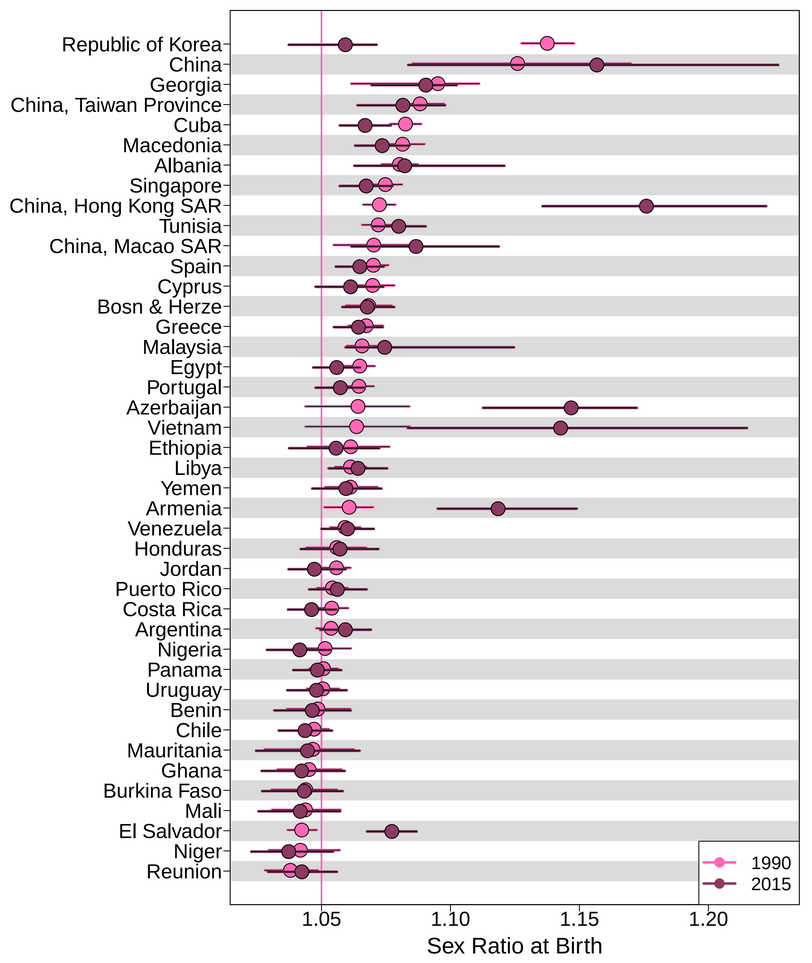


Figure: **Countries with outlying SRB estimates in 1990 and/or 2015.** "Outlying" means the 95% CI does not include its corresponding regional norm. *Note: data quality issues may partially explain outlying SRBs in some identified countries.

Result 4: Global and Regional SRB

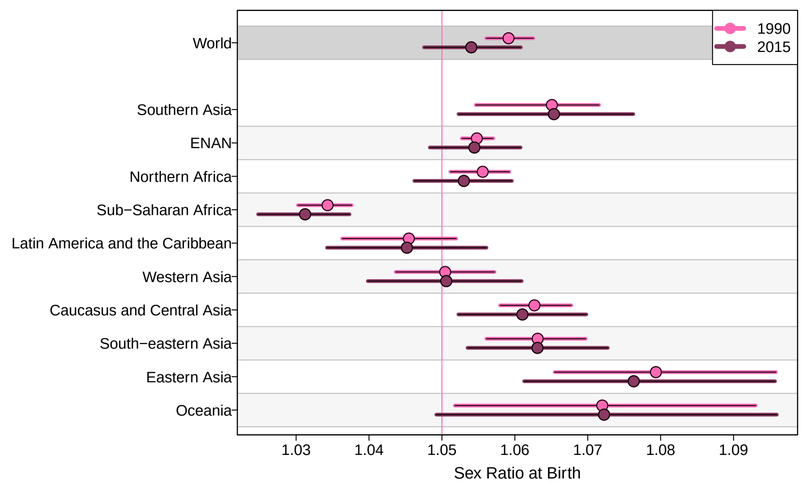


Figure: **Sex ratio at birth for the world and regions in 1990 and 2015.** Region "ENAN" refers to the combination of countries in Europe, North America, Australia, and New Zealand.

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