A Systematic Assessment of National, Regional and Global Levels and Trends in the Sex Ratio at Birth and Identification of Countries with Outlying Levels

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Extended Abstract for PAA 2018

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1 Introduction

In this paper, we describe a method for probabilistic estimation and projection of the sex ratio at birth (SRB; ratio of male to female live births) for all countries, with a focus on assessing the SRB imbalance due to sex-selective abortion.

Under normal circumstances, the SRB varies in a narrow range around 1.05, with only a few known variations among ethnic groups (1; 2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 12). For most of human history, the SRB remained within that natural range. However, over recent decades, SRBs have risen in a number of Asian countries and in Eastern Europe (13; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23; 24; 25; 26; 27; 28; 29). The increasing imbalance in SRB is due to a combination of three main factors that lead to sex-selective abortion (21; 23). Firstly, most societies with abnormal SRB inflation have persisting strong son preference, which provides the motivation. Secondly, since the 1970s, prenatal sex diagnosis and access to sex-selective abortion have become increasingly available (30; 31; 32; 33; 34), providing the method. Thirdly, fertility have fallen to low levels around the world that resulted in a "squeezing effect": to attain both the desired small families and the desire of sex composition by resort to sex selection (21). Consequently, sex-selective abortion provides a means to avoid large families while still having male offspring.

Estimation of the degree of SRB imbalance is complicated by the amount of uncertainty associated with SRB observations due to data quality issues and sampling and stochastic errors, which in turn makes projection difficult. While the UN Population Division publishes estimates and projections for all countries in the World Population Prospects (WPP), its estimates and projections are deterministic, and depend on expert-based opinions which are not reproducible (35). The current methodology in the UN's WPP 2017 version for SRB projections are based on the basic assumption of a natural level of SRB at 1.05, and future SRB outcomes either remain at the same level as the most recent data or return towards the natural level within the next 10–40 years. An up-to-date systematic analysis for SRB–one of the most fundamental demographic indicators–for all countries over time using all available data with reproducible methods for estimation and projection is urgently needed.

To fill the research void, we developed model-based estimates and probabilistic projections from 1950 to 2100 for 212 countries (referring to populations that are considered as "countries" or "areas" in the United Nations classification) with total population size greater than 90,000 as of 2015. Our analyses are based on a comprehensive database on national-level SRB with data from vital registration (VR) systems, censuses, international and national surveys. We developed two Bayesian hierarchical models to estimate and project SRBs in two types of country-years: 1) those that are not affected by sex-selective abortion, and 2) those that may be affected by sex-selective abortion that leads to unnatural SRB inflation.

2 Data

Data on births by sex are recorded in vital registration (VR) systems, or in censuses or surveys with retrospective questions on recent births or full birth histories asked to women of reproductive ages. VR systems typically provide data on an annual basis, while censuses usually provide information for the previous 12 or 24 months, and surveys for longer retrospective periods from 5 to 20 years before the survey date when using full birth histories.

An overview of the data sources included in the database is in Table 1. There are 9,929 data points available from 194 out of the 212 countries that we estimated and projected the SRB. In total, there are 15,354 country-years available in our database. On average, 72.4 country-years of data are available for each of the 212 countries included in the analysis.

3 Summary of Methods

We conducted a systematic literature review on Feb 22nd, 2017 to identify countries with empirical evidence of SRB inflation, as well as countries with populations that are considered to have a son preference or to be a patrimonial society. By searching the keywords "sex selective abortion" on PubMed, we found 416 articles. By searching the keywords "son preference" or "patrimonial society" on Scopus, there were 526 articles in the search result. By going through the abstract and conclusion of the 942 articles, we selected 31 articles that identified countries with SRB inflation and/or having a son preference on the national level. The selected articles are listed in Table 2. Besides

Data source type	Number of observations
Census	61
DHS	2,005
Other DHS	886
Other	151
VR/SRS	6,826
total	**9,929**

Table 1: **Distribution of observations by source type.** Observations are grouped by source type. DHS: Demographic and Health Surveys, where Other DHS refer to non-standard Demographic and Health Surveys, i.e. Special, Interim and National DHS, Malaria Indicator Surveys, AIDS Indicator Surveys and World Fertility Surveys; VR: Vital Registration; SRS: sampling registration system.

countries that were identified by the systematic literature review, we also considered a country to have a potential for SRB inflation if it was identified as having an outlying female under-5 mortality rate in the year 2015 (36; 37), or if recent records of the desired sex ratio at birth are higher than 120 and/or the sex ratio of last birth is higher than 130 (14). In total, we identified 33 countries at risk of SRB inflation as listed in Table 2, which satisfy at least one of the aforementioned criteria.

To model SRB in country-years not affected by sex-selective abortion, we developed a model for natural fluctuations in the SRB and fitted it to the global database after excluding data from country-years with potential SRB inflation. The actual level of SRB was modeled as the product of a biological norm and a country-year-specific multiplier that accounts for natural fluctuation around the norm. We allowed biological norms to differ across regions to incorporate SRB differences due to ethnicity (1; 2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 12). Hence, for this purpose, regions refer to groupings of countries based on their majority ethnicity. For example, we grouped countries in Europe, North America, Australia, and New Zealand to refer to the regional grouping of countries with a majority of Caucasians. Within each region, we assumed that the biological norm was constant over time. We modeled the true SRB $R_{c,t}$ for country c, year t without SRB inflation as follows:

$$R_{c,t} = N_{r[c]} \cdot P_{c,t}, \tag{1}$$

where $N_{r[c]}$ is the regional biological norm from country c in region $r[c]$ in the absence of prenatal sex discrimination and sex-selective abortion and $P_{c,t}$ is the divergence from that norm under natural circumstances.

To model SRB in country-years affected by sex-selective abortion, we parameterized the potential SRB inflation in the 33 countries at risk of SRB inflation using a trapezoid to represent consecutive phases of increase, stagnation, and a decrease back to zero (see Figure 1). Parameters were estimated with a Bayesian hierarchical model (60) to share information across countries about the start year of the inflation, the maximum inflation, and the length of the inflation period during the three phases. We incorporated the effect of the fertility squeeze into the model by using the total fertility rate (TFR, obtained from UN WPP 2017 (35)) to inform the mean of the distribution of start year of the SRB inflation period. The mean for the start year was determined by an analysis of the relation between TFR and the start year as observed in countries with high quality VR data. Given that the inflation in India started at an unusually high TFR, the start year for this country was not estimated as part of the hierarchical model. Instead, a uniform distribution was assigned to allow any start year between 1970 and 1980. Hence, the true level of SRB $R_{c,t}$ for country c in year t with rick of SRB inflation due to selective abortion is modeled as follows:

$$R_{c,t} = N_{r[c]} \cdot P_{c,t} + \alpha_{c,t}, \tag{2}$$

where the additional term $\alpha_{c,t}$ is the upward inflation factor for country c in year t to capture higher SRB levels that may be due to sex-selective abortion.

For those countries at risk of SRB inflation without empirical evidence of an inflation during the observation period, referred to as countries at risk of future SRB inflation, SRB projections were constructed based on two scenarios: 1) no SRB inflation will occur, i.e. the SRB will fluctuate around its respective regional biological norm in future years; and 2) the SRB will inflate due to sex-selective abortion for some future period (as determined by the hierarchical model for SRB inflation and the country-specific TFR projections).

Country	(1) Inflated SRB	(2) Excess female U5MR	(3) High DSRB	(4) High SRLB	(5) Son preference	Reference
Afghanistan		✓				(37)
Albania	✓					(38)
Algeria		✓				(37)
Armenia	✓		✓	✓	✓	(28; 17; 21; 14)
Azerbaijan	✓		✓	✓	✓	(28; 17; 21; 14)
Bangladesh					✓	(39; 40)
Chad			✓			(14)
China	✓				✓	(24; 22; 41)
Egypt		✓			✓	(37; 42; 43; 44; 45; 46)
Georgia	✓				✓	(28; 17; 21)
Guinea			✓			(14)
Hong Kong SAR (China)	✓					(13)
India	✓	✓	✓	✓	✓	(24; 47; 38; 14; 37)
Iran		✓				(37)
Jordan		✓	✓	✓		(37; 14)
Korea, Republic of	✓				✓	(29; 21)
Mali			✓			(14)
Mauritania			✓			(14)
Montenegro	✓					(38)
Morocco					✓	(42)
Nepal		✓	✓	✓	✓	(37; 14; 48; 49; 50; 51)
Niger			✓			(14)
Nigeria					✓	(52; 53)
Pakistan	✓	✓	✓	✓	✓	(21; 14; 37)
Senegal			✓		✓	(14; 54)
Singapore	✓					(55; 56)
Taiwan province (China)	✓					(27)
Tanzania					✓	(57)
Tonga		✓				(37)
Tunisia					✓	(42)
Turkey					✓	(58)
Uganda					✓	(59)
Vietnam	✓				✓	(20)

Table 2: **Countries with past/current/potential future SRB inflation.** Selection criteria 1–5 are: 1. Literature suggests inflated past or current SRB; 2. The sex ratio of the under-five mortality rate (U5MR) is outlying and associated with excess female deaths, which may be caused by postnatal gender discrimination (2015 UN IGME report (36); with "outlying" defined in Alkema et al. 2014 (37)); 3. The desired sex ratio at birth (DSRB) is higher than 120 male births per 100 female births as suggested in Bongaarts 2013 (14); 4. The sex ratio of last birth (SRLB) is higher than 130 male births per 100 female births based on Figure 3 in Bongaarts 2013 (14); 5. Literature reports on son preference or patrimonial society.

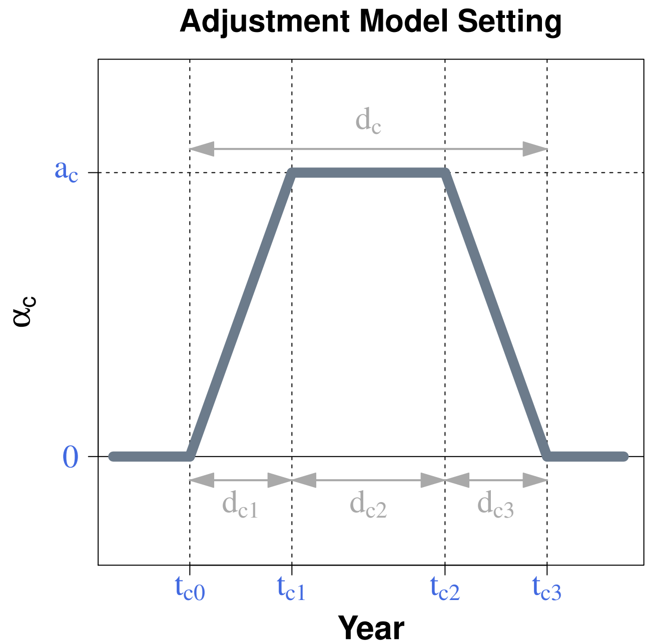

Figure 1: **Illustration for model setting of the inflation factor.** $t_{c,0}$ and $t_{c,3}$ refer to the start and end year of SRB inflation period for country c. d_c is the total length of the SRB inflation period for country c. a_c is the maximum value of the inflation value in country c.

4 Selected Findings

The SRB estimates and projections for ten example countries are illustrated from three groups: 1) Figure 2: countries without risk of SRB inflation; 2) Figure 3: countries with past and ongoing SRB inflation; and 3) Figure 4: countries at risk of future SRB inflation.

Sweden, Guatemala, and Zimbabwe are examples of countries without risk of SRB inflation (Figure 2). Sweden typifies countries with high quality annual VR data, here available from 1753 to 2013. SRB model estimates follow the VR data trend and the uncertainty assessment takes into account the stochastic uncertainty associated with the VR data. The estimated SRB for Sweden ranges from 1.04 [1.04; 1.05] in 1774 to 1.06 [1.06; 1.07] in 1953. The SRB has fluctuated around its corresponding regional norm for the region of ENAN at 1.06 since around 1900. The SRB projection for Sweden is approximately constant and given by its regional norm, with the projection for 2100 given by 1.06 [1.03; 1.08]. Guatemala, a lower-middle income country from Latin America and the Caribbean, has data from VR as well as surveys. The data period is from 1948 to 2011. The estimated SRB for Guatemala was the highest in 1959 at 1.05 [1.04; 1.06] and was the lowest in 2010 at 1.03 [1.02; 1.04]. The SRB estimates are mostly informed by the VR data since the VR data have less uncertainty associated with them as compared to survey data. The projection for Guatemala slowly converges from 1.03 [1.02; 1.04] in 2011 towards its regional norm 1.04, and is expected to eventually reach 1.04 [1.01; 1.06] in 2100. Lastly, Zimbabwe, a low-income country in Sub-Saharan Africa, only has survey data that are subject to large sampling errors. Its SRB was estimated slightly above its regional biological norm 1.03 during the early data period from 1972 to 1995, and was estimated to be approximately equal to its regional biological norm after 1995. The SRB for Zimbabwe in 2100 is projected to be 1.03 [1.00; 1.05].

Azerbaijan, India, China, and Republic of Korea are example countries with past and ongoing SRB inflation (Figure 3). The TFR estimates and projections for these four countries are overlaid on to the SRB estimates in the figure, to illustrate the relationship between the start year of the SRB inflation period and the fertility decline, as incorporated into the model to estimate the start year of the inflation period. For example, the start year of the SRB inflation period for Azerbaijan is estimated to be 1990, which corresponds to the year in which the TFR decreased to 3.1. The start year in China is estimated to be 1981 when its TFR decreased to 2.6. India is a country with an outlying high TFR value of 5.2 at the start of its inflation period in 1975. The maximum SRB estimates for all these 4 countries during the inflation period have already occurred during their data periods. In Azerbaijan, the SRB has reached its maximum at 1.17 [1.16; 1.19] in 2007. The SRB in China and India peaked at 1.20 [1.16; 1.25] in 2006 and at 1.11 [1.10; 1.13] in 2003 respectively. The maximal SRB in Republic of Korea occurred in 1991 at 1.14 [1.13; 1.15]. Based on the model projections, the SRB will converge or has converged back to the range of natural fluctuations in the 2030s for Azerbaijan, in 2020s for China, in 2016 for India, and in 2008 for the Republic of Korea. The recent SRB convergence for India is largely informed by the sample registration system data between 2007 and 2011.

For the countries at risk of future SRB inflation, estimates and projections that are based on the inclusion and the exclusion of future inflation are illustrated for Egypt, Mali, and Nepal (Figure 4). As the data in these countries do not suggest SRB inflation during the observation periods, the projections without future inflation all converge from the estimates at the end of data period to the regional biological norms. When assuming that inflation does occur, the start year of the SRB inflation in Egypt is projected to be in the 2030s, in Mali in the 2060s, and in Nepal in the 2010s, corresponding to the year when TFR projections in these countries decrease to around 2.8.

5 Discussion

Our study is the first systematic analysis of the SRB for all countries that produces annual estimates and scenario-based projections from 1950 to 2100. We have compiled an extensive SRB database to include all available data from national vital registration systems, international surveys on full birth history, censuses, and national-level surveys and reports. These were synthesized using a Bayesian hierarchical model for estimation and projection, which allows sharing of information between data-rich country-years and neighboring country-years with limited information or without data. The model produces probabilistic projections based on certain scenarios and model assumptions.

The natural level of SRB is related to individual-level factors including maternal or paternal age at conception, birth order, sex of the preceding child, maternal weight, family size, environment condition for mother during pregnancy i.e. the Trivers-Willard hypothesis, as well as ethnicity (61; 62; 63; 64; 65; 66; 67; 68; 69; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 12). While most of the information is not available for the aggregate level data we collated, we aimed to estimate the differences in SRB due to ethnicity, which we approximated by grouping countries from similar regions or with similar ethnicities due to European colonization. Further refinements of the grouping are possible, e.g. to divide Sub-Saharan Africa into smaller regions since there is additional heterogeneity in the biological SRB levels within the region (2; 3; 8), or to divide Latin America and Caribbean into two sub-regions because of the majority of African ancestry in the Caribbean countries. However, in the absence of unanimously agreed regional groupings, we opted for larger aggregations in this study.

Our study analyzed the national-level SRB, which may mask the disparities of SRB within countries. Future work should assess subnational divisions in countries with outlying SRB to better understand where female births are most discriminated against in the prenatal period. In addition, without a full understanding of the subnational SRB, we are not able to conclude that the prenatal sex discrimination did not exist in countries that are normal at the national-level. Hence, subnational-level SRB studies based on reproducible methods for countries with or without imbalanced national-level SRB are urgently needed.

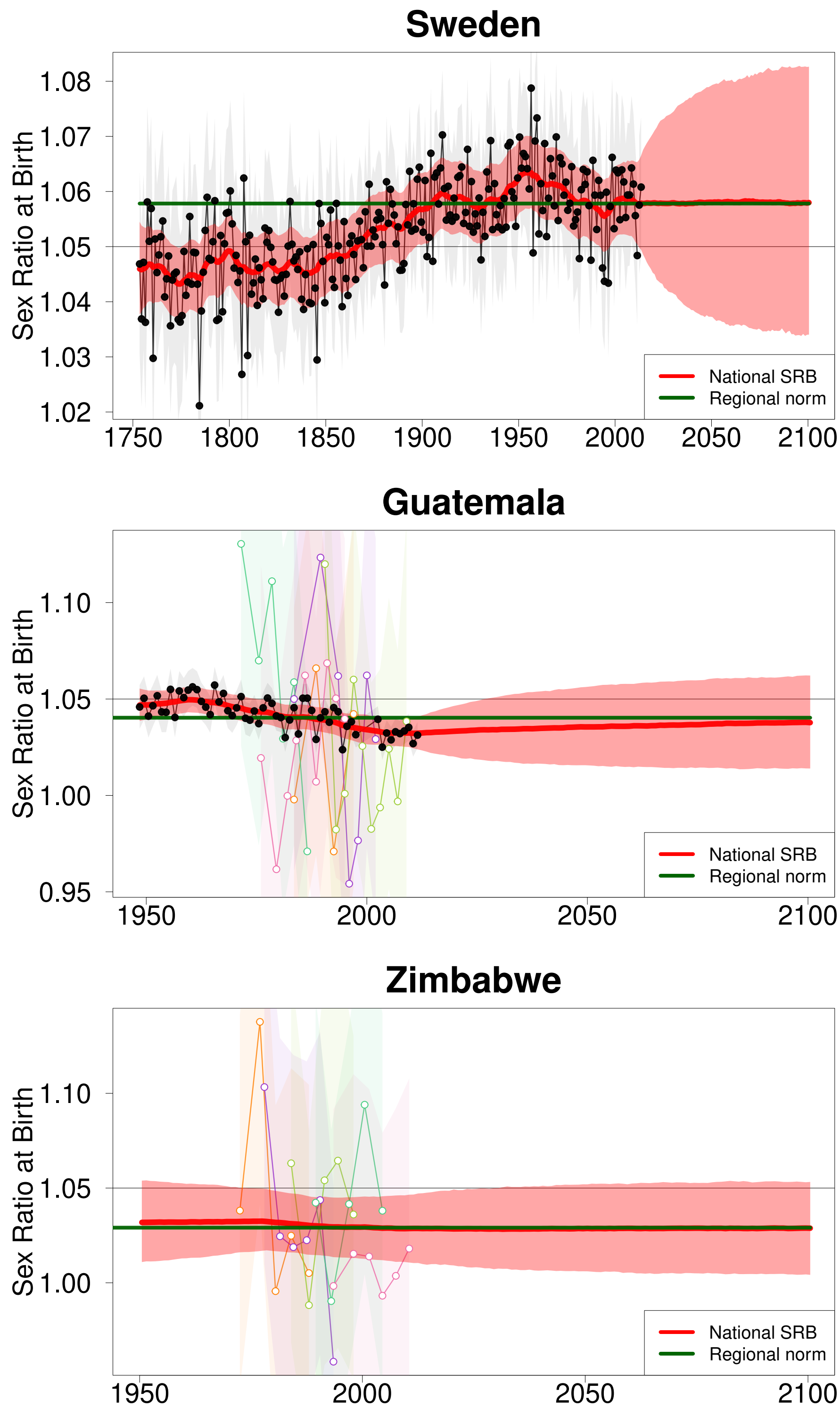

Figure 2: **SRB estimates and projections for example countries without inflation.** The green horizontal lines are the estimates for the regional biological norm of SRB. The red lines and shaded areas are the country-specific SRB estimates and their 95% uncertainty intervals. Observations from different data series are differentiated by colors. The shaded areas surrounding observations represent the sampling or stochastic errors associated with the observations.

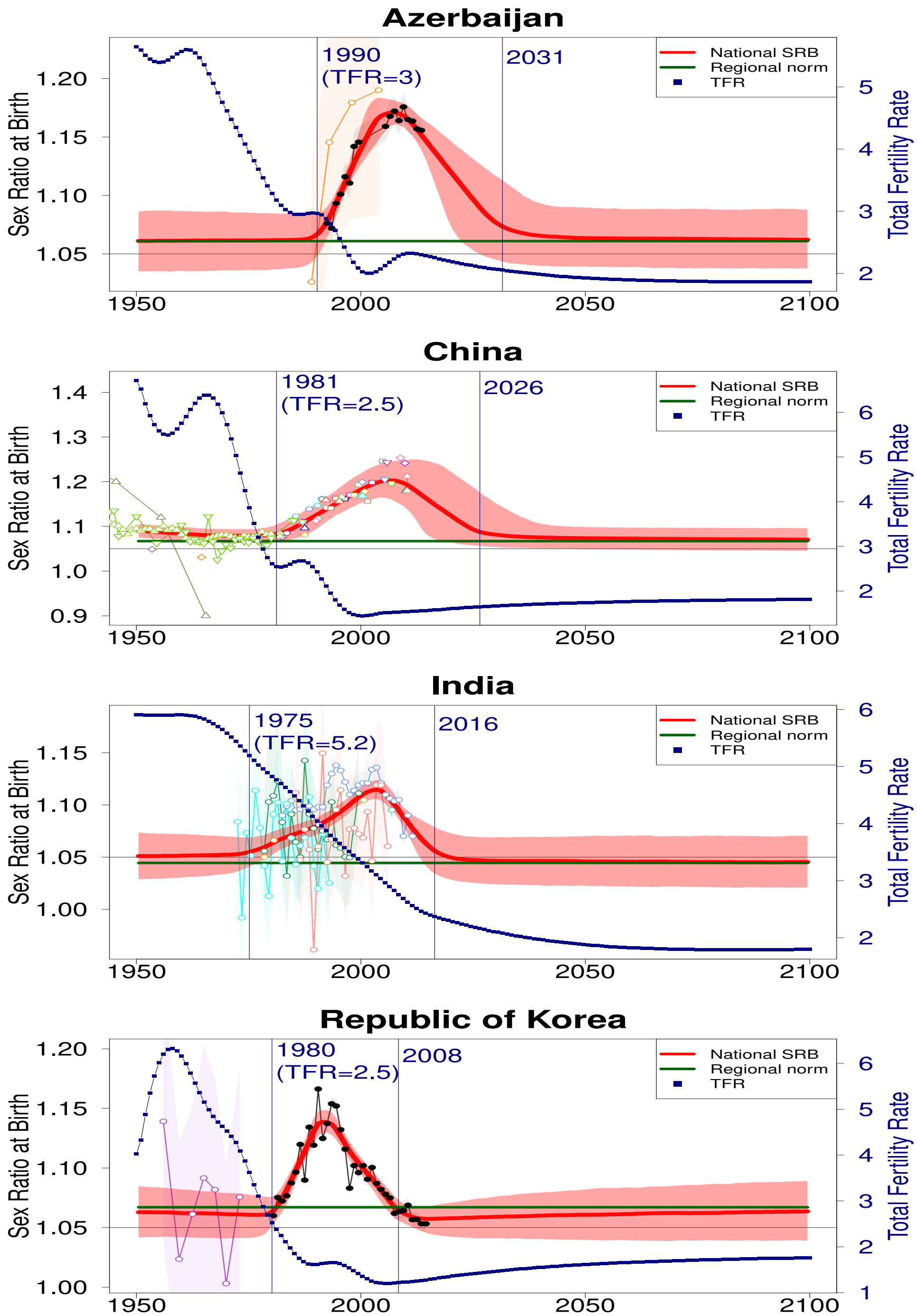

Figure 3: **SRB estimates and projections for example countries with past/ongoing inflation.** The green horizontal lines are the estimates for the regional biological norm of SRB. The red lines and shaded areas are the country-specific SRB estimates and their 95% uncertainty intervals. The blue square dots are UN WPP 2017 total fertility rate estimates and median projections. The two blue vertical lines indicate the median estimates for start and end years of SRB inflation period. The TFR values in the start years of SRB inflation periods are shown. Observations from different data series are differentiated by colors. The shaded areas surrounding observations represent the sampling or stochastic errors associated with the observations.

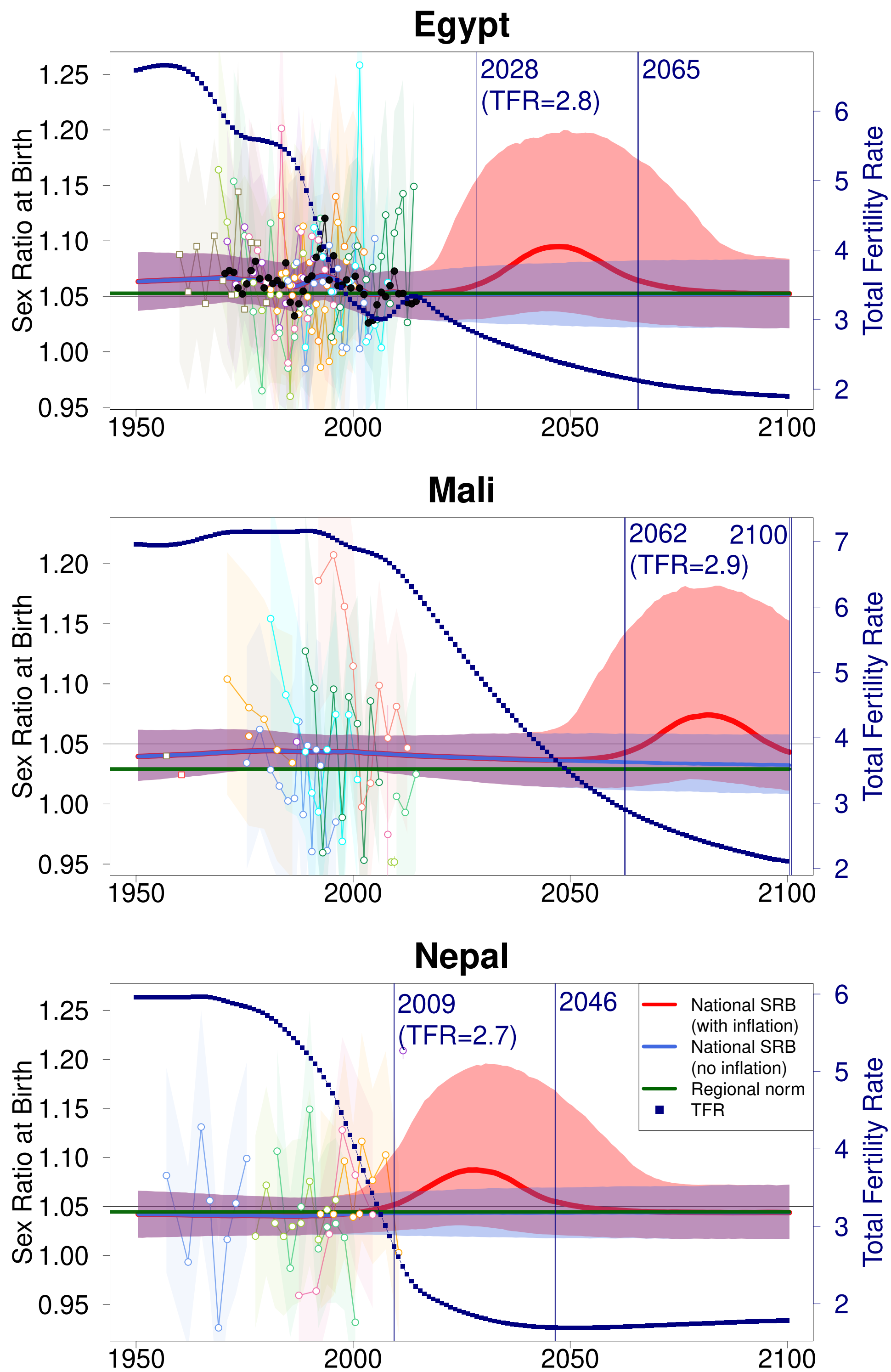

Figure 4: **SRB estimates and projections for example countries at risk of future SRB inflation.** The green horizontal lines are the estimates for the regional biological norm of SRB. The red lines and shaded areas are the country-specific SRB estimates and their 95% uncertainty intervals for scenario 1: with SRB inflation in projection period. The blue lines and shaded areas are the country-specific SRB estimates and their 95% uncertainty intervals for scenario 2: no SRB inflation in projection period. The blue square dots are UN WPP 2017 total fertility rate estimates and median projections. The two blue vertical lines indicate the median estimates for start and end years of SRB inflation period. The TFR values in the start years of SRB inflation periods are shown. Observations from different data series are differentiated by colors. The shaded areas surrounding observations represent the sampling or stochastic errors associated with the observations.

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