The Dynamics of Prenatal Sex Selection and Excess Female Child Mortality in Contexts with Son Preference

Ridhi Kashyap
Nuffield College



A thesis presented for the degree of
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Thesis Abstract

This thesis examines demographic manifestations of son preference in three parts. Part I develops a simulation model that formalises the decision to practice prenatal sex selection through a "ready, willing and able" framework. The model is calibrated to South Korean and Indian sex ratio at birth (SRB) trajectories. Simulations reveal how SRB distortions in both countries have emerged despite declining son preference due to the rapid diffusion of ultrasound combined with growing propensities to abort as a result of weakening norms for large families. Part II examines the potential role of big data to indirectly estimate the SRB at the subnational level in India. States with distorted SRBs tend to display a relatively high Google search activity for ultrasound. SRB "now-casts" generated using search volumes perform better than lagged variable models in high birth registration states. Part III examines the relationship between prenatal sex selection and postnatal excess female child mortality in two studies. The first applies lifetable techniques to decompose population changes in child sex ratios into a fertility component attributable to prenatal sex selection and a mortality component attributable to sex-differentials in postnatal survival. This study finds that although reductions in numbers of excess female deaths have accompanied increases in "missing" female births in all countries experiencing SRB distortions, excess female mortality has persisted in some but not in others. The second study uses birth histories of the Demographic and Health Surveys for six countries that have witnessed SRB distortions – India, Nepal, Pakistan, Azerbaijan, Armenia and Albania – to examine if differential mortality change by sex can be explained by the uptake of prenatal sex selection. This study finds that changes in prenatal sex selection only explain mortality change in India. Across all countries, although patterns of mortality disadvantage are concentrated amongst less educated mothers, prenatal sex selection is strongest among the better educated. Differential sorting into the two behaviours offers an explanation for why the effect for prenatal sex selection is generally weak.

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For my DPhil, I had the luxury of having two academic homes – one in Oxford at Nuffield College and the Department of Sociology, and the other in Rostock at the Max Planck Institute for Demographic Research (MPI). I feel extremely fortunate to have benefited from the financial and intellectual resources available in both of these communities. At MPI, the institute's directors Jim Vaupel (in the first two years) and Mikko Myrskylä (in the third year) generously agreed to support my project. In the first year of my PhD, Frans Willekens's insightful lectures during his course on simulation approaches in demography at the MPI stirred my interests in the topic. During the course, ideas for part I of this thesis were generated and Francisco (Pancho) Villavicencio, a fellow course mate, agreed to come on board with taking it forward. Pancho was a terrific co-author and I am thankful for his contributions to the two papers in part I of this thesis. During the 2015–2016 academic year, I was a member of Mikko's fertility and well-being lab at MPI, and got to spend a year during an exciting and dynamic time at the institute. I attended several interesting seminars, participated in academic courses, and above all, had the support of excellent friends and colleagues at MPI. I am grateful to Mikko and members of his labs for these opportunities. In particular, Tim Riffe provided valuable insights for chapter 6 of this thesis. For chapter 7, I am grateful to Kieron Barclay for liberally sharing his time for several brainstorming discussions and for his guidance with DHS data. Daniel Schneider made technical problems seem easy to solve with his programming tips.

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Chapter 1

Introduction

1.1 Background

Starting in the late 1980s and early 1990s, a number of countries in East, South and West Asia, including South Korea, China, India, Azerbaijan, among others, witnessed steady increases in the proportion of male births relative to female births (Guilmoto, 2015). This proportion has been conventionally expressed in demography in terms of the sex ratio at birth (SRB), which refers to the number of live male births for every 100 female births in a given year.[1] According to United Nations demographic estimates available since the 1950s, the SRB in most countries has been largely stable hovering between 104 – 106 male births per 100 female births (United Nations, 2015a). By the middle of the 1980s, SRBs in South Korea first rose from 106 to levels exceeding 112 within the span of a decade (Park and Cho, 1995). SRB trajectories in China, north and northwest India, and countries of the Caucasus followed the same course a few years later in the 1990s making the emergence of SRB distortions one of the "most notable anomalies in contemporary demography" (Guilmoto, 2009, p. 519). The SRB went from

[1]Some demographic literature and datasets (e.g the United Nations World Population Prospects) refer to the ratio in terms of the number of male births for every 1 female birth (United Nations, 2015a). In contrast to the international convention, Indian demographic literature and sources such as the Census refer to sex ratios with the female count in the numerator and male count in the denominator. This thesis will adopt the international convention and always refer to sex ratio quantities with the male count in the numerator.

being demographic indicator that was previously secondary to the analysis of population dynamics to an indicator of widespread interest to demographers and policy makers.

Prenatal sex selection, most commonly in the form of sex-selective abortion of female foetuses, was deduced to be the proximate cause of the SRB distortions (Bongaarts, 2013; Guilmoto, 2009; Park and Cho, 1995). Son preference can cause parents to continue childbearing until they have a son or more likely to use contraception when they bear a son (Bongaarts, 2013). Although such sex-differential stopping rules can impact overall fertility levels, the sibling configuration of families, and the sex ratio at last birth in populations, only prenatal sex selection can distort probabilities of male birth, as indicated by the population's SRB.[2] The timing of SRB distortions in the 1980s and 1990s coincided with the growing availability of cheap and effective ultrasound technology, which facilitated prenatal sex determination of the foetus, enabling couples who might previously have proceeded to higher parity births the opportunity to reconcile a preference for male offspring with that for smaller families (Guilmoto, 2009). The increasing masculinisation of the SRB thus became a modern manifestation of a long-standing norm guiding fertility behaviour widely described in the demographic literature as son preference.

The influence of patriarchal gender systems on son preference has long been noted by demographers of the developing world.[3] A number of scholars, par-

[2]The implications of sex preferences for macro-level fertility outcomes or sibling configurations within families had been shown by formal demographic treatments by Sheps (1963) and Yamaguchi (1989). Sheps (1963) deduced the population-level implications of sex preferences for total fertility levels showing that sex preferences would increase overall levels of fertility if parents restricted family size based on the existing sex composition of children compared to a population without sex preferences. Yamaguchi (1989) demonstrated how son-preferring differential stopping behaviour would result in girls being born into larger families. This has been shown empirically for India in Clark (2000) and insights from Yamaguchi's approach have been extended by Basu and De Jong (2010). Using the South Korean case, Park (1983) showed how sex-differential stopping behaviour resulted in highly masculine sex ratios at last birth for families in a population.

[3]Sex preferences and their influence on fertility behaviours has also been noted by scholars writing on contemporary Europe and the United States (Mills and Begall, 2010; Andersson et al., 2006; Pollard and Morgan, 2002). In particular, the focus of these studies has been on

ticularly in studies of South Asia, ascribed son preference to women's economic dependency on men within patriarchal family systems in which men were the primary wage earners and land inheritors, and sons were the primary source of financial support in old-age (Cain, 1993; Miller, 1987; Cain et al., 1979). For East Asian societies, son preference was widely attributed to Confucian values and low levels of female autonomy (Croll, 2000). Instead of local or context-specific explanations, comparative studies such as Das Gupta et al. (2003) have underscored the importance of the persistence of patrilineal family systems where conventionally property, names and titles are transferred along the male line in explaining son preference across the diverse contexts of South Korea, China and India. The rules of marriage in such systems also tend to emphasise patrilocality, wherein daughters move into their husband's family and away from their natal families upon marriage. Whether or not such kinship systems give rise to dowry, by virtue of their "organisational logic" they generate strong incentives to bear at least one son.

Although some degree of son preference in terms of expressed preferences have been noted across much of the world (Fuse, 2010; Williamson, 1976), the strength of son preference in parts of South Asia and East Asia, the Middle East and parts of North Africa has been strong enough to leave its mark on population structures in the form of a female deficit in population sex ratios (Bongaarts and Guilmoto, 2015). The economist Amartya Sen famously described this phenomenon in terms of girls and women being "missing" from population structures (Sen,

the impact of the sex of existing children on the transition to third birth (Hank, 2007). In the US, over the course of the twentieth century studies reported that parents with two children of the same sex were more likely to transition to third births than parents with children of each sex, indicating a tendency towards a balanced sex composition. This effect has weakened considerably in recent years (Pollard and Morgan, 2002). In the Nordic countries, a daughter preference has been reported (Andersson et al., 2006). A growing literature has also examined the sex-selective behaviours of Asian immigrants in Europe and North America. These studies have found distorted SRBs among immigrants of Indian and Chinese origin in England and Wales (Dubuc and Coleman, 2007), Indian and Pakistani mothers in Norway (Singh et al., 2010), Chinese and Indian mothers in the US (Abrevaya, 2009) and Canada (Almond et al., 2013).

1990). When Sen first coined the term "missing women", most missing women were attributable to the excess mortality risks resulting from systematic patterns of gender discrimination. Following Sen's landmark essay, a number of demographers sought to refine his estimates of the numbers and age patterns of missing women by using different standards of expected sex ratios of mortality and population structures (Bongaarts and Guilmoto, 2015; Klasen and Wink, 2003; Coale, 1991).

A key finding of these studies was the concentration of excess female mortality in the ages of childhood. The notion of excess here implies that girls faced higher than biologically expected mortality risks given prevailing overall levels of mortality. Girls' excess mortality risks were attributed to either direct infanticide or the unequal allocation of resources such as healthcare and nutrition within families (Jayachandran and Kuziemko, 2011; Borooah, 2004; Li et al., 2004; Croll, 2000). More recent scholarship has emphasised how excess mortality may also emerge indirectly through the fertility effects of son preferring stopping rules. These stopping rules result in girls being born into larger families (Basu and De Jong, 2010; Clark, 2000), which, assuming net resources per child are fewer in larger families than smaller ones, results in their greater mortality risks at the aggregate level (Barcellos et al., 2014; Rosenblum, 2013).

Missing women in populations now reflect a combination of prenatal sex selection and postnatal excess female mortality (Bongaarts and Guilmoto, 2015). Although the practice of prenatal sex selection as indicated by SRB distortions has been identified in countries where manifestations of son preference in the form of excess female mortality have previously been noted (e.g China, India), the two different practices of sex selection and their demographic manifestations do not necessarily overlap. For example, although countries of the Middle East and North Africa have often been identified as countries with strong son preference and anomalous sex ratios of mortality indicative of excess female mortality

(Alkema et al., 2014; Sawyer, 2012; Tabutin and Willems, 1995), SRB distortions have not been noted in these contexts. Conversely, countries of Southeast Asia have generally been noted as countries with weak or no son preference and no systematic patterns of excess female mortality. Nevertheless, Vietnam has been identified as having outlying SRB levels since the mid-2000s (Guilmoto, 2012b). SRB distortions have appeared in often disparate demographic contexts, ranging from those with higher fertility and mortality in South Asia such as India and Nepal, to lower fertility contexts such as China, South Korea and Vietnam, as well as the Caucasus and Balkan countries including Azerbaijan, Armenia, Georgia or Albania (Guilmoto, 2015; Frost et al., 2013; Guilmoto and Duthé, 2013; Duthé et al., 2012; Park and Cho, 1995). Moreover, SRB trajectories across these disparate contexts have taken different shapes and attained different peak levels, as indicated in Figure 1.1.

In light of the shifting demographic manifestations of son preference, a number of questions arise. How do we characterise and understand the micro-level behaviours underpinning macro-level SRB trajectories that take varied forms across different demographic regimes? How do we appropriately measure and anticipate patterns of change in SRBs, particularly when data on abortion or ultrasound access are not readily available, and birth registration data are often inadequate? How do temporal changes in the SRB relate to changes in other demographic manifestations in son preference, most notably patterns of excess female mortality? Does the uptake of prenatal sex selection lead to reductions in excess female mortality in populations with son preference?

This thesis tackles these questions in three parts. Part I and II address prenatal sex selection and take the SRB as the primary demographic quantity of interest. Part III addresses how changes in prenatal sex selection are related to changes in patterns of postnatal excess female mortality. Part I develops a simulation model of the decision to practice prenatal sex selection to explore

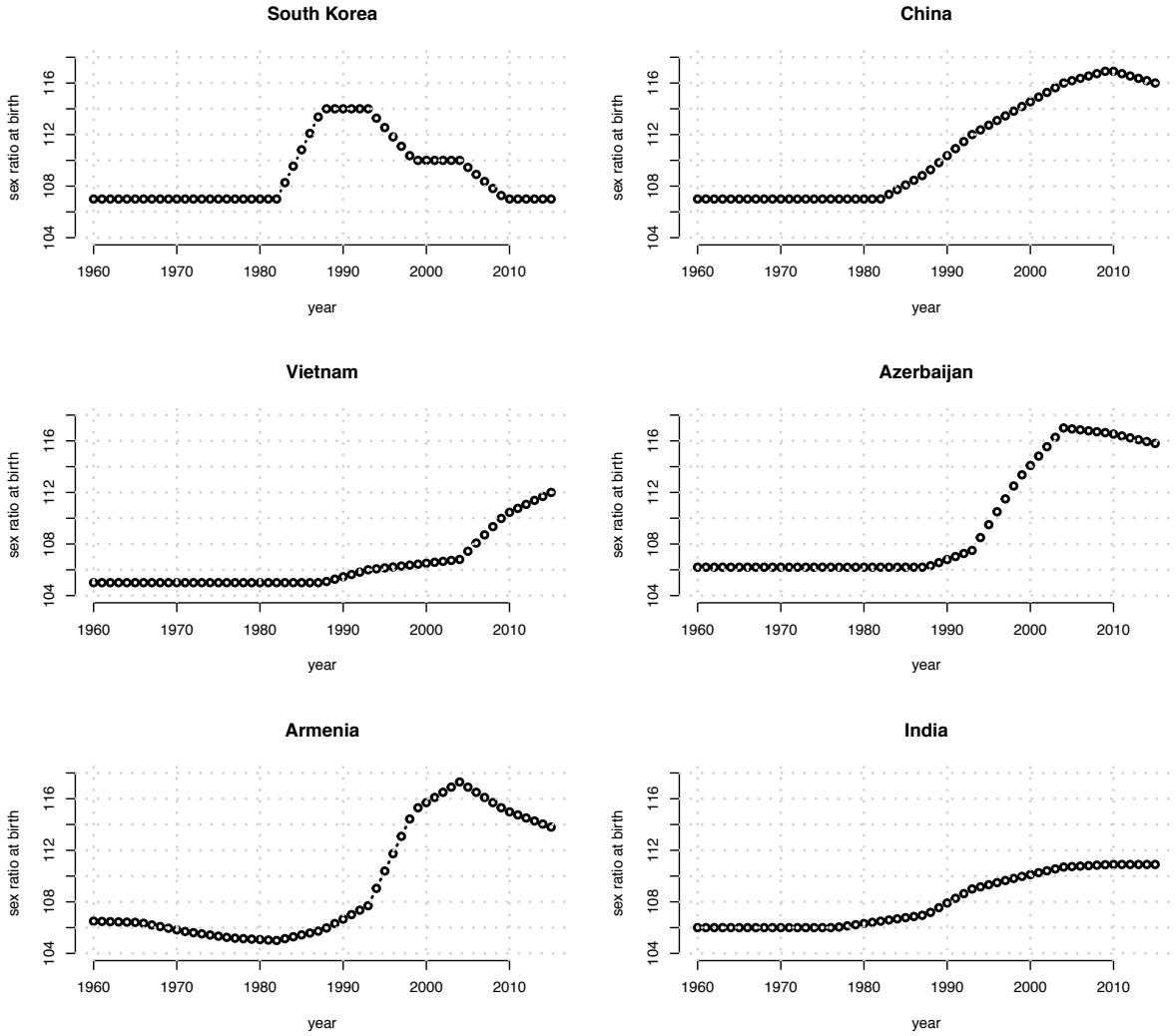


Figure 1.1: Sex ratio at birth (SRB) by year for select countries. Data from United Nations (2015a).

the micro-level processes that cause macro-level SRB distortions. Part II investigates the potential use of web search data to study SRBs at the subnational level in India and to capture the 'digital footprints' of underpinning micro-level processes. Part III studies the relationship between prenatal sex selection and postnatal excess mortality. In what follows, I first present gaps in the literature that motivate different parts of the thesis and describe how the studies presented address them. I then highlight the methodological innovations adopted in the thesis to tackle the research problems. The first two parts of the thesis draw on computational approaches of individual-based simulation, the use of web data for demographic estimation and regression methods oriented towards prediction from machine learning, which are still nascent in the demographic literature. The third part uses traditional tools of demographic analysis, such as life table and event history techniques.

1.2 Motivation

1.2.1 Demographic Modernisation and Son Preference

Increases in masculinity of SRBs and child sex ratios witnessed across several countries in Asia and the Caucasus in the 1990s appeared to be a paradoxical development in light of the wider social and economic changes that were taking place in these societies (Chung and Das Gupta, 2007a). Social and demographic theorists had assumed that modernisation forces that made women educated, productive and brought about other state-based forms of social insurance for parents would erode the incentives to bear sons across developing countries (Croll, 2000, p. 109). Implicit in demographic accounts of son preference was the idea that the preference was a manifestation of early-transitional demographic regimes of high fertility and mortality. Son preference, it was assumed, kept fertility levels higher than they would be in its absence and also resulted in higher than

biologically normal expected levels of mortality for girls (Arnold et al., 1998; Nath and Land, 1994; Cain, 1993; Amin and Mariam, 1987; Cain et al., 1979).

Following from this line of thought, theoretical accounts assumed that low fertility brought about by the demographic transition would combine with greater industrialisation and urbanisation to shift families away from the extended patrilineal form, in which sons are imperative for family continuity, towards nuclear forms with more equitable sex roles (Goode, 1963). In similar terms, theorists of gender systems and demographic change described the potential of the demographic transition to bring about a transition in gender systems (Mason, 1993). Greater autonomy for women in the economic sphere, through pathways such as expanding female educational opportunity and labour market participation, or through the weakening of patriarchal and patrilineal family systems was hypothesised as eroding norms for sons, which stemmed from the low status of women in societies with low female autonomy (Mason, 2001, 1993, 1986; Dyson and Moore, 1983). Whether through pathways of family change, or through socio-economic mechanisms, these accounts predicted a weakening of son preference with demographic modernisation.

Even as macro-level sex ratio distortions worsened, indicators of stated son preference weakened in the direction of gender equality as predicted by the demographic modernisation accounts. These stated son preference indicators generally relied on desired fertility questions asked in fertility surveys such as the desired number of sons and daughters. In their analysis for north India using these ideal fertility questions from the Indian National Family Health Survey, Bhat and Zavier (2003) noted how the proportions of sons in the ideal family size for mothers appeared to decline as the ideal number of children declined. Similarly, Chung and Das Gupta (2007a) reported a steady decline in the proportion of women who reported it "necessary to have a son" in South Korea in the 1980s and 1990s. More recently, Bongaarts (2013) has studied patterns of son preference across the

populations of diverse low- and middle-income countries for which Demographic and Health Survey data were available. He found that although son preference in a population as measured in terms of the desired sex ratio at birth (DSRB), an indicator computed as the ratio of the ideal number of sons to the ideal number of daughters, varied in intensity across populations, son preference was generally stronger in high fertility societies than in low fertility contexts.

Why then did SRBs worsen even though indicators of son preference appeared to shift in directions of greater gender equality? In attempting to reconcile these ostensibly paradoxical trends, studies such as Bhat and Zavier (2003) and Chung and Das Gupta (2007a) acknowledged the role of the technological diffusion of ultrasound in contributing to masculine sex ratios amidst declining son preference. Guilmoto (2009) provides a useful framework to describe the micro-level preconditions of the practice of prenatal sex selection borrowing from Ansley Coale's 'ready, willing and able' (RWA) framework originally used by Coale to explain fertility decline in nineteenth century Europe. The individual decision to practice prenatal sex selection in this framework can be conceptualised as the outcome of three processes: 1) individuals must be 'willing' to consider sex selection because of strong son preference norms; 2) individuals must be 'able' to consider sex selection because of the availability of prenatal sex determination technology such as ultrasound as well as access to abortion; 3) individuals must be 'ready' to practice prenatal sex selection as a consequence of norms for smaller families that become widespread as fertility declines causing families to choose abortion over progression to higher parities to realise their son preference.

Each of these conditions is necessary for the practice of prenatal sex selection. Although son preference may then be widespread across different contexts, as studies such as Bongaarts (2013) indicate, SRB distortions may not occur there due to either limited ability on account of either limited access to ultrasound or abortion in the population, or due to limited readiness emerging from taboos

or laws against abortion that might discourage the widespread uptake of sex-selective abortion. In sub-Saharan African contexts, John Bongaarts has argued that limited ability of ultrasound may explain why SRBs remain normal (Bongaarts, 2013). On the other hand, in Muslim contexts of the Middle East such as Iran and Egypt, as well as Pakistan, Islamic taboo against abortion may explain why SRBs generally have remained within normal ranges even though son preference has been documented in terms of excess female mortality and differential stopping behaviour (Zaidi and Morgan, 2016; Hessini, 2007). Similarly, abortion may not be legal in other contexts. For example, abortion was only legalised in 2002 in Nepal and this is likely a contributing factor to why SRB trajectories rose later there than in its neighbour India (Frost et al., 2013).

Part I of the thesis develops and applies a micro-founded simulation model of the RWA framework to understand the plausible levels, trends and interactions of son preference, technology diffusion and fertility decline that underpin macro-level SRB trajectories. Chapter 2 describes the model. In Chapter 3, I analyse the model's behaviour by calibrating it to South Korean SRB trajectories. This analysis provides novel insights on how SRB levels and trajectories respond to different parameters of readiness, willingness and ability within populations. In Chapter 4, I further extend the model to the Indian case. By calibrating the model to both Indian and South Korean trajectories, the model highlights how the three common processes of readiness, willingness and ability can generate the two distinctive SRB trajectories of the two countries (see Fig. 1.1).

1.2.2 Tracking Sex Ratio at Birth Patterns

Although Guilmoto lucidly describes the three preconditions that cause SRB imbalances using the RWA framework, he acknowledges that existing data preclude a "more detailed decomposition... of these distinct dimensions" in explaining observed SRB levels and trends (Guilmoto, 2009, p. 535). Data on ultrasound

availability and use over time to approximate the timeline and variations of ultrasound diffusion and data on the practice of induced abortion are not readily available. This makes it hard to disentangle the relative contributions of declining son preference, increasing technology access and the role of fertility decline in determining the shape of macro-level SRB patterns. Furthermore, this poses a challenge for determining the future course of SRB trajectories. In this data sparse context, the simulation model presented in Part I provides a potential tool to combine available data sources and reconcile patterns of change in the factors underpinning the uptake of prenatal sex selection.

A different, perhaps more basic type of challenge also affects the ability of demographers to estimate and monitor SRB trends. Although the SRB is simply a ratio of male to female births, computing this straightforward ratio requires reliable birth registration data. However, in a number of populous countries such as China, India, or Nepal, civil registration data suffer from a number of problems. Either civil registration is incomplete, or data quality varies at the subnational level (Guilmoto, 2015; Attané and Guilmoto, 2007). Sample surveys provide an alternative source for the estimation of the SRB. The SRB is simply a transformation of the proportion of male births. The precision of SRB estimates derived from birth histories from surveys is highly sensitive to sample size and making inferences about systematic deviations from normal SRB levels requires reliably large samples of births (Arnold et al., 2002). Although population censuses are often used as a source to indirectly estimate the SRB, censuses are large undertakings for which data are only released infrequently. The SRB, thus, despite being a straightforward indicator can be a difficult one to reliably track.

Part II of this thesis addresses this problem by examining the potential of web search data as a tool to track the SRB. Since ultrasound availability is a key precondition for SRB distortions, Google search data provide a potential indication of the interest and uptake of the technology. Chapter 4 of the thesis

examines the feasibility of this data source to study variations in subnational patterns of the SRB in India, and compares predictions of the SRB from Google search based models and lagged variable models.

1.2.3 Prenatal Sex Selection and Postnatal Excess Female Child Mortality

The existing literature documents how son preference is manifested in both prenatal sex selection and postnatal excess mortality. The preconditions underlying prenatal and postnatal manifestations of son preference are quite different. Postnatal excess female mortality is more likely to occur in contexts where norms for larger family sizes prevail and families practice sex-differential stopping behaviour to achieve their son preference (Bongaarts, 2013). Here, mortality differentials resulting from high fertility behaviour are likely to emerge (Rosenblum, 2013; Jayachandran and Kuziemko, 2011; Muhuri and Preston, 1991). Prenatal sex selection on the other hand is more likely to be practiced in societies where parents prefer to keep their families small by practicing abortion instead of proceeding to additional births and ultrasound is more widely available. Consequently, the relative demographic contribution of prenatal and postnatal manifestations of son preference to missing girls in the population is likely to vary by the stage of the demographic transition that a population is in. Furthermore, changes in prenatal sex selection may influence changes in postnatal excess female mortality. If an important factor underlying postnatal excess mortality is child unwantedness, the increasing adoption of sex-selective abortion may plausibly imply better survival chances for those girls who are born as they are more likely to be wanted (Goodkind, 1996).

Part III of this thesis examines the relationship between prenatal sex selection and postnatal excess female child mortality. I adopt different data sources and approaches to study the relationship. First, in chapter 6 I develop a macro-

demographic approach using country-level lifetable data for the period between 1980 to 2015 to study the interplay between sex imbalances at birth and sex-differentials in child mortality. I decompose changes in child sex ratios into a 'fertility' component attributable to prenatal sex selection and a 'mortality' component attributable to sex-differentials in postnatal survival to assess how each component changes within countries over time in countries that have witnessed SRB distortions. In chapter 7, I use data from the birth histories of the Demographic and Health Surveys of six countries where prenatal sex selection has been deduced to underlie SRB distortions – India, Nepal, Pakistan, Azerbaijan, Albania and Armenia. Using these micro-level data, I investigate the impact of prenatal sex selection on relative mortality changes for girls versus boys. Do changes in prenatal sex selection drive mortality change in the population or are the two processes unrelated to one another? The micro-level birth histories provide further information on subsets of populations who practice the two different strategies of sex selection, as well as a better understanding of the patterns of mortality disadvantage by the sibling composition of families.

1.3 Methodological Approaches

1.3.1 Individual-based Simulation Techniques

The three parts of this thesis adopt different approaches to demographic analysis. From a methodological perspective, Part I of the thesis illustrates how individual-based simulation models can help link micro-processes of individual decision-making to macro-demographic phenomenon. Agent-based and microsimulation models are a class of individual-based computational modelling methods that have been proposed as a valuable set of techniques to model emergent demographic phenomena through the simulation of heterogeneous individuals who follow behavioural rules and adapt their behaviours in response to stimuli (Bil-

lari and Prskawetz, 2003). Through the use of the simulation model presented in Part I, I illustrate how a simple, behavioural model of individual decision-making in the form of the RWA framework can be applied to explain the emergence of macro-level SRB patterns.

The model combines data on demographic rates and fertility preferences from different sources to simulate what Bijak et al. (2013) call a "semi-artificial population". The idea of the semi-artificial population model bridges the two distinct simulation traditions of microsimulation and agent-based modelling, which although methodologically similar in their reliance on individuals as the unit of analysis and the use of computer algorithms to determine transitions between states, have been applied for different purposes (Zagheni, 2015). Due to their use for projection purposes, microsimulation models are often 'data-heavy' and rely on empirical transition rates. Agent-based models have often been used as artificial laboratories to test behavioural theories or the implications of theories for macro-level patterns with the aim of describing emergent regularities.

The two traditions, however, at least with respect to demographic applications do not need to be separate. A model to test a theory of population change can be better validated by incorporating information on demographic rates when they are available, as well as using different data sources that may be relevant to the question under study. Similarly, a plausible and well-calibrated agent-based model can be a potentially useful tool for population predictions. Even if the estimates generated by an ABM informed population projection are similar to those that come from standard population projection techniques such as parametric or time-series models, the data-generating mechanism and scientific approach underpinning the two models are different. Parametric models can be considered, to borrow from the categorisation of demographic approaches provided by Billari (2015), a part of the toolbox of macro-demographic approaches, which attempt to find mathematical or statistical models that best describe given data without pro-

viding an underlying rationale for the data-generating process at the individual level. A population prediction generated from an agent-based or microsimulation model, however, generates an outcome in which a macro-level regularity emerges from a set of rules that are formalised and are consequently meaningful at the individual level. This technique provides a way to link the micro-level behaviours to macro-level outcomes (Van Bavel and Grow, 2017; Billari and Prskawetz, 2003).

By incorporating demographic data within a simulation model, we can make it less artificial by rendering it more realistic representation of the individuals that we seek to describe. Nevertheless, by virtue of being a model to describe population change, it remains an abstraction and a simplification of one set of mechanisms that explain a population phenomenon. The RWA simulation model presented in this thesis can be interpreted in this sense as a semi-artificial population model. It uses data, where available and appropriate, and implements it within a behavioural framework to show its feasibility as a tool for explanation. By combining different data within one framework to generate a population that behaves according to a set of rules, the simulation model helps clarify and reconcile patterns of change in different underlying behaviours, such as weakening son preference and increasing access to prenatal sex determination and uptake of prenatal sex selection at the individual-level, which may not be clear from purely macro-level description. Moreover, by adopting approaches to the sensitivity analysis of simulation models as advocated by Grow (2017) and Bijak et al. (2013), as well as by developing counterfactual scenarios, the model can help reveal how SRB levels and trajectories respond to different patterns of change in both micro- and macro-level conditions.

1.3.2 Big Data for Indirect Estimation

Part II of the thesis considers the role of one form of 'big data' – digital trace data in the form of Google web searches – for indirect estimation and short-term

prediction of the SRB at the subnational (state) level in India. Digital trace data refer to data that are left behind as a result of social interaction on digital spaces and outlets, as well as digital records that are created as a result of the use of web tools such as search engines (Manovich, 2011). These data are different from conventional social science data sources in that they were not especially designed for social research in the same way that data sources such as surveys or censuses are (Ang et al., 2013).

Although the use of digital trace data in population studies is nascent, digital trace data have been adopted to study demographic topics such as migration (Zagheni et al., 2014; Zagheni and Weber, 2012), abortion (Reis and Brownstein, 2010) and health (Nguyen et al., 2015; De Choudhury et al., 2013). Zagheni and Weber (2012) used geo-referenced Yahoo! email data to estimate profiles of international migration by age and sex, and Zagheni et al. (2014) used geo-located Twitter data to study short-term migrations in OECD countries. Reis and Brownstein (2010) and Nguyen et al. (2015) used data on Google search volumes to study abortion and chronic disease risk respectively in the US. Reis and Brownstein (2010) found that the intensity of abortion searches at the state-level in the US was inversely related to the restrictions imposed upon abortion in those states. Similarly Nguyen et al. (2015) found Google searches about risk factors for diseases was positively correlated with chronic disease prevalence at the level of US states, and used search data to predict chronic disease prevalence. Examining behavioural cues over the course of the preceding year on the Twitter profiles of individuals who had self-identified as being clinically depressed, De Choudhury et al. (2013) predicted the probabilities of depression based on their social media posting patterns.

As the discussion above highlights, a key focus of the burgeoning literature using digital trace data for demographic topics has been on using these data as a potential tool for estimation and prediction. This is not surprising given that

digital trace data provide 'real-time' information about a population that can be implemented to develop 'now-casts' or short-term forecasts informed by real-time, dynamic information in a way that slower data sources such as surveys or censuses do not. Furthermore, these data may provide insight into potentially taboo topics or topics for which data may not be as easily available in other sources, as exemplified by the study by Reis and Brownstein (2010). Although the examples discussed above generally refer to the applications of big data for research on developed countries, there is growing interest in the utility of big data in developing countries as a tool for tracking human development indicators over time and space in data-sparse settings (Letouzé and Jütting, 2014). For example, Blumenstock et al. (2015) used information on mobile phone use by an individual over time to predict his or her socioeconomic status in Rwanda. At the population-level, mobile phone behaviours were then used by the authors to predict wealth distributions in the country where official statistics are often inadequate or not systematically collected.

Following from the discussion above, chapter 5 of this thesis uses data from Google search volumes related to ultrasound and sonography, both at the national level and at the level of Indian states, to assess whether these data track the regional and temporal dynamics of SRBs, complementing existing estimates and developing now-casts for state-level SRBs for 2014 to 2016. These data provide new sources of information in a context where the timeline of diffusion of ultrasound technology is not well documented across states. The existing literature has shown how SRBs in India have often been the most distorted amongst the educated and richer social groups, which has in turn been attributed to their better access to ultrasound technology (Guilmoto, 2015; Jha et al., 2011). It is plausible then that online information plays a role in facilitating access to and knowledge about ultrasound for these social groups. Working from the assumption that Google search volumes provide insight on the interest and uptake of ultrasound

in the population, and similar to other studies exploiting digital trace data, the study puts the search data to predictive use. It draws on prediction-oriented techniques developed in the machine learning literature, specifically regression methods with rectangularisation, to exploit the use of these data for this purpose (Tibshirani, 2011).

1.3.3 Macro- and Micro-demography

Part III of this thesis adopts tools from, to borrow again from the characterisation in Billari (2015), the two distinct traditions of demographic analysis – the macro-demographic and micro-demographic. Macro-demographic approaches, such as formal demographic techniques, are useful for describing population change to aid the "discovery" of patterns and regularities in demographic phenomenon. Chapter 6 of this thesis develops and applies a lifetable framework to country-level demographic data from the United Nations (2015a) to quantify the contribution of prenatal sex selection and postnatal excess female child mortality to sex ratio dynamics at childhood ages. This approach enables a macro-level description of the components underpinning changes in sex ratios, and allows for an understanding of these changes over time within countries. The analysis is global in scope although the exposition focuses more on countries where both prenatal and postnatal forces are at play in population dynamics – in South Asia (India, Nepal and Pakistan), East Asia (South Korea, China, Vietnam), and the Caucasus and Balkans (Armenia, Azerbaijan, Georgia, and Albania).

Micro-demographic perspectives are rooted at the individual level and seek to find explanations for patterns of population change. This search for explanation draws on methods such as event history analysis applied to surveys, which enable a closer look at variations across individuals and subgroups of individuals. Chapter 7 adopts a micro-demographic approach to study the dynamics of mortality and prenatal sex selection as revealed by micro-level data from birth histories

from the Demographic and Health Surveys. This data source facilitates a closer examination of patterns of mortality disadvantage for girls, such as by sibling composition as well as an understanding of variations in the practice of prenatal and postnatal manifestations of sex selection by maternal education across six countries where SRB distortions have been noted in existing literature. The analysis presented in this chapter seeks to examine if changes in prenatal sex selection have been a mechanism for change in sex-differentials in child mortality.

Part I

A Simulation Model of Sex Ratio at Birth Distortions

Chapter 2

An Application of the 'Ready, Willing and Able' Framework to Prenatal Sex Selection

2.1 Introduction

Since the 1980s and 1990s, several countries in Asia and the Caucasus have witnessed a rise in the proportion of male births compared with female births, conventionally expressed in terms of the sex ratio at birth (SRB) (Guilmoto, 2009, 2015).[1] The rise in SRBs within a short span of time, usually a decade or less, make this trend unprecedented and the sizeable populations where it has been noted—China, India, South Korea, Vietnam, Georgia, Azerbaijan, among others—make it one of the "most notable anomalies" of contemporary demography (Guilmoto, 2009, p. 519). Earlier literature presumed that widespread son preference would keep fertility levels higher than they would be in its absence and would delay the fertility transition (Amin and Mariam, 1987; Cain, 1993; Nath and Land, 1994). In recent decades, however, SRBs have risen because technology – most commonly in the form of ultrasound – that enables couples to resort to sex-selective abortion has spread in contexts where couples continue to

[1] Chapters 2, 3 and 4 present joint work co-authored with Francisco Villavicencio. Material from Chapter 2 and 3 has been published as Kashyap, R., and F. Villavicencio."The Dynamics of Son Preference, Technology Diffusion, and Fertility Decline Underlying Distorted Sex Ratios at Birth: A Simulation Approach." *Demography* 53.5 (2016): 1261-1281.

desire at least one son while seeking to keep their family size small.[2] This has led demographers to speculate that SRBs may rise in other contexts where son preference persists but safe, effective and cheap sex determination technology has yet to become available (Bongaarts, 2013).

The causes, patterns and demographic implications of imbalanced SRBs remain the subject of a large and growing body of research. Extensive demographic research has paid attention to highlighting SRB levels and trends in comparative perspective (Attané and Guilmoto, 2007; Duthé et al., 2012; Guilmoto, 2009; Bongaarts, 2013; Guilmoto, 2015). In contrast, comparatively less attention has been paid to understanding the levels and trends of micro-level dynamics underlying SRB trajectories. Given this lacuna in the literature, Guilmoto (2009) presented a framework for the three micro-level preconditions—persistent son preference, declining total family size and the spread of sex-selective abortion technology—leading to the practice of prenatal sex selection. In the same paper, Guilmoto also developed a framework for understanding macro-level SRB trajectories in terms of an "archetypal transition cycle" involving a rise, levelling off and eventual decline towards normalcy that he terms the "sex ratio transition".

Although Guilmoto lucidly described the three preconditions that cause SRB imbalances, he acknowledged that existing data preclude a "more detailed decomposition... of these distinct dimensions" in explaining observed SRB levels and trends (Guilmoto, 2009, p. 535). The literature has not attempted to quantify, for example, what levels and rates of change in son preference over time, rates of technological diffusion and probabilities of sex-selective abortion plausibly underpin observed SRB and fertility trajectories. Furthermore, the impact of

[2]Sex-selective abortion requires prenatal sex-determination technologies as well as methods for abortion. Different technologies for prenatal sex-determination technologies presently exist: amniocentesis, an invasive procedure that is conducted between 15 and 20 weeks of pregnancy, ultrasonography, which can determine the sex of the foetus as early as 11 weeks, and blood tests involving the analysis of the foetal DNA floating in the mother's bloodstream, which are minimally invasive procedures that can be done at home as early as 7 weeks into the pregnancy (Bongaarts, 2013). Ultrasound is the most widely used technology for prenatal sex determination (Ganatra, 2008).

sex-selective abortion on reducing fertility as distinct from a population that exclusively practices differential stopping behaviour (DSB) has not been explicitly addressed. Differential stopping behaviour (DSB) refers to fertility behaviour in which couples continue childbearing until they reach a desired number of sons by regulating their contraceptive use based on the sex composition of existing children. Several papers report the presence of DSB—manifested in higher levels of contraceptive use after bearing sons, higher levels of parity progression in daughter-only families, or high sex ratios at last birth—across different son-preferring populations (Amin and Mariam, 1987; Arnold et al., 1998; Bongaarts, 2013; Clark, 2000; Larsen et al., 1998; Retherford and Roy, 2003).

This chapter presents a microsimulation model that simulates individual-level reproductive behaviours bottom-up to examine emergent population-level SRB trajectories. In the model, individuals who desire a son practice differential stopping behaviour. Although these individuals wish to control their total fertility levels as time moves on, their son preference does not always allow them to stop childbearing at low parities. Technology then emerges as an exogenous stimulus that diffuses steadily in the population enabling growing proportions of individuals to reconcile their son preference with their aspirations for smaller families. The proportion of individuals desiring sons, their total fertility levels, and those with access to technology all change over time at differing rates, and their interactions produce aggregate SRB trajectories. We first develop a general model that allows us to describe and formalise the micro-level processes that generate SRB distortions. We adapt the general model to enable calibration with United Nations World Population Prospects (UN WPP) data on mortality, fertility and population structure (United Nations, 2013).

The chapter proceeds as follows: the first part of the chapter highlights the importance of understanding the micro-level mechanisms underpinning SRB distortions and a framework for doing so. We then describe microsimulation and

agent-based modelling approaches in demography to motivate their application in this case to the practice of prenatal sex selection. The second part of the chapter describes the microsimulation model, including the state variables, initialisation, and reproductive behaviours and related parameters that make up the model.

2.2 Theoretical Background

2.2.1 Micro-dynamics and SRB distortions

From a theoretical standpoint, the steep rise in SRBs and child sex ratios across Asia and the Caucasus despite rapid modernisation and development posed a severe challenge to demographic and social theory (Chung and Das Gupta, 2007a; Croll, 2000). The same modernisation forces that made women educated, productive, and ensured other forms of social insurance for parents were implicitly assumed to erode the norms of son preference as well. Parents would no longer want children for extra labour, income, or social status (Croll, 2000, p. 109)—factors that were thought to underpin son preference in pre-transitional societies. Moreover, low fertility would combine with greater industrialisation and urbanisation to shift families away from the extended patrilineal form, in which sons are imperative for family continuity, towards nuclear forms with more equitable sex roles (Goode, 1963). However, contrary to theoretical expectations, even as levels of fertility steadily declined in the 1980s and 1990s across South Korea, China and India, skewed SRBs seemed to suggest that son preference persisted.

A number of significant studies have noted how indicators of stated son preference, measured in different ways, appeared to decline even as sex ratios worsened (Bhat and Zavier, 2003; Bongaarts, 2013; Chung and Das Gupta, 2007a). In attempting to reconcile these ostensibly paradoxical trends, Bhat and Zavier (2003) in their systematic analyses of changing stated son preference and total ideal family size in north India were among the first to suggest the role of

technological diffusion in contributing to masculine sex ratios amidst declining son preference. Existing studies have noted this explanation but not explicitly modelled the interplay of son preference with technology diffusion and fertility decline at the individual-level and linked them to macro-level SRB trajectories. This study highlights and extends insights on the micro-level underpinnings of SRB trajectories.

2.2.2 The Sex Ratio Transition

Guilmoto (2009) provided a valuable theoretical framework of the micro-level factors underpinning macro-level SRB distortions. The recent rise in SRBs across Asia, he argued, "resembles a diffusion process similar to that sometimes claimed to be characteristic of a fertility decline" (Guilmoto, 2009, p. 524). By likening the shape of the SRB transition to the fertility decline, Guilmoto adapted Ansley Coale's well-known 'ready, willing and able' (RWA) approach (Coale, 1973), originally used by Coale to account for the European fertility decline in the nineteenth century, to the practice of sex selection. To explain the fertility decline in Europe, Coale posited that three conditions had to be met: (1) Were individuals *willing* to limit fertility? This condition required that limiting fertility had to acceptable and not proscribed by existing normative considerations (e.g religious or ethical) that individuals adhered to. (2) Did parents have access to technology (e.g contraception) to be able to limit family size? This condition described the *ability* of parents to limit fertility. (3) Were parents *ready* to limit their family size? The readiness condition brought in considerations of utility, that is, limiting fertility had to be economically advantageous to the actor within their decision-making calculus.

In their more general reformulation of Coale's classic framework, Lesthaeghe and Vanderhoeft (2001) highlighted its usefulness as a conceptual apparatus in social demography to explain adaptation to new modes of behaviour involving

processes of innovation and diffusion. In the same paper, the authors also applied the framework to the study of fertility transitions in the developing world underscoring its wider applicability beyond the setting for which it had originally been developed. The strength of the RWA conceptual framework, they argued, is in its ability to integrate economic and noneconomic paradigms that include normative legitimacy, economic utility, as well as functional considerations of technological access in explaining adaptations to new behaviours. Moreover, by explicitly identifying distinctive causal processes underlying the uptake of new behaviour, the RWA framework highlighted how transitions to new forms of behaviour can take different forms depending on differing rates and patterns of change in each of the R, W and A components.

The RWA conceptual framework can be applied to the proximate causal processes underlying the practice of sex selection. From the "actor's point of view", sex selection can be seen as "a rational strategy in response to changing constraints and opportunities within existing gender regimes" (Guilmoto, 2009, p. 526). The practice of sex selection from the actor or individual's perspective can be seen as the outcome of three conditions being met: (1) The actor must be *willing* to consider sex selection because of the persistence of cultural norms that reinforce the value of male offspring. Sex preferences must be entrenched within a social and cultural context that allow agents to consider acting on them. Across the diverse contexts of South and East Asia where strong SRB distortions have been observed, Das Gupta et al. (2003) have argued that son preference is underpinned by commonalities in patrilineal and patrilocal kinship systems that reinforce the material and ideological value of male offspring. (2) Actors must be *able* to access sex-selective abortion due to the availability of relatively affordable and accurate prenatal sex determination technology to detect the sex of the foetus, as well as have access to abortion that enables them to abort it when unwanted. (3) Even in the presence of son preference (*willingness*) and access to

technology (*ability*), actors will not perform sex selection unless they are *ready* to do so. The idea of readiness usually gains importance in low fertility situations with the diffusion of norms towards smaller families wherein deliberate sex selection becomes a preferable goal instead of additional births as the means to realise son preference. Guilmoto described the costlier trade-off between higher parity births and the realisation of son preference with declining fertility in terms of a 'fertility squeeze' that determines the readiness to practice sex selection.

In the same paper, Guilmoto speculated whether South Korean SRB trajectories may be a manifestation of an "archetype transition cycle" involving three phases: at first a rise, second a levelling off, and a third phase involving a decline and eventual return to normal levels—that may eventually come about across other parts of Asia where similar SRB distortions have been observed. Although the return to normal levels suggestive of a completed transition has only been observed in South Korea, the first (steep rise) and second (levelling off) phases have also been observed in the trajectories of other countries, such as China, India, Azerbaijan, Armenia and Georgia as well. These SRB trajectories are shown in Fig. 2.1.

What factors underpin the different phases of SRB trajectories? Bongaarts (2013) conceptualised SRB levels as linked to the different stages of the fertility transition. In early-transition societies with high levels of fertility where fertility control has not been widely adopted, SRB levels are likely to remain normal. In these societies, son preference levels are also likely to be high. As fertility control becomes more widespread in mid-transition societies, the interaction of the desire to restrict family size combined with stable son preference, is likely to result in the increase in the SRB. Guilmoto characterises this in terms of the fertility squeeze that generates the the readiness to abort in the RWA framework, and several other scholars have linked the onset of SRB distortions to the diffusion of small family norms (Goodkind, 2015; Frost et al., 2013; Duthé et al., 2012). Fig. 2.2

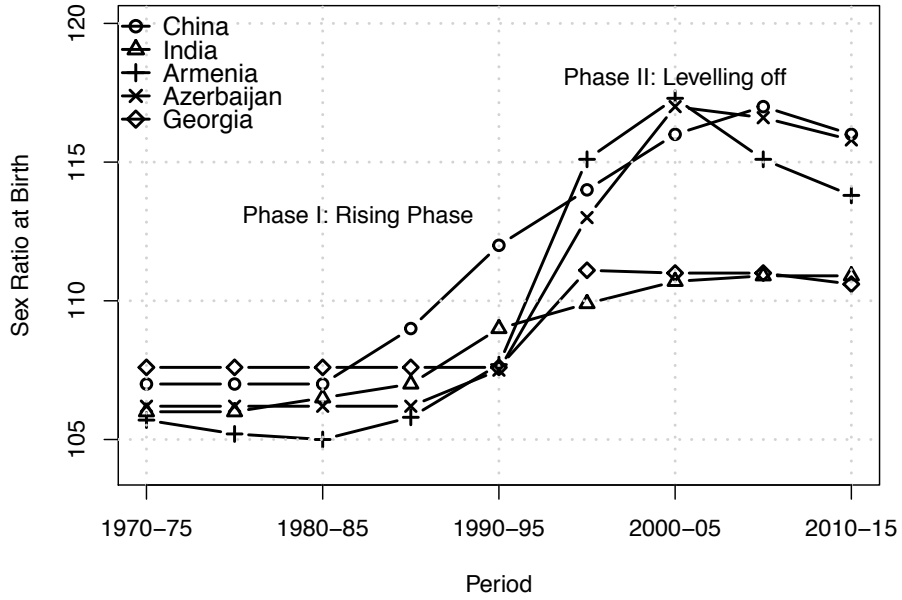


Figure 2.1: Sex ratio at birth (SRB) trajectories for countries that have witnessed levels of 110 male births per 100 female births in their rising phase (phase I) and have begun to level off (phase II). Data source: United Nations (2015a)

shows the SRB as a function of the TFR for countries in South, East and West Asia that have witnessed SRB distortions. In general, the smoothed relationship between the two variables as indicated by the grey line in the figure suggests that SRB levels appear to rise as fertility falls, with a turnaround evident at lowest-low levels of fertility, such as those witnessed in South Korea.

Nevertheless, this figure also highlights how SRB distortions can emerge in quite diverse fertility regimes and how SRB levels can reach very different levels at generally similar levels of fertility. There is no specific level of the total fertility rate (TFR) at which SRB distortions appear to emerge, with countries such as India witnessing distortions at considerably higher levels of the TFR. On the other hand in contexts such as Armenia and Georgia, SRB distortions emerge at much lower levels of the TFR at levels at around or below 2. The rise in their SRB trajectories, as also highlighted in Fig. 2.1 is much steeper than those in India. This highlights the importance of considering the role of the other

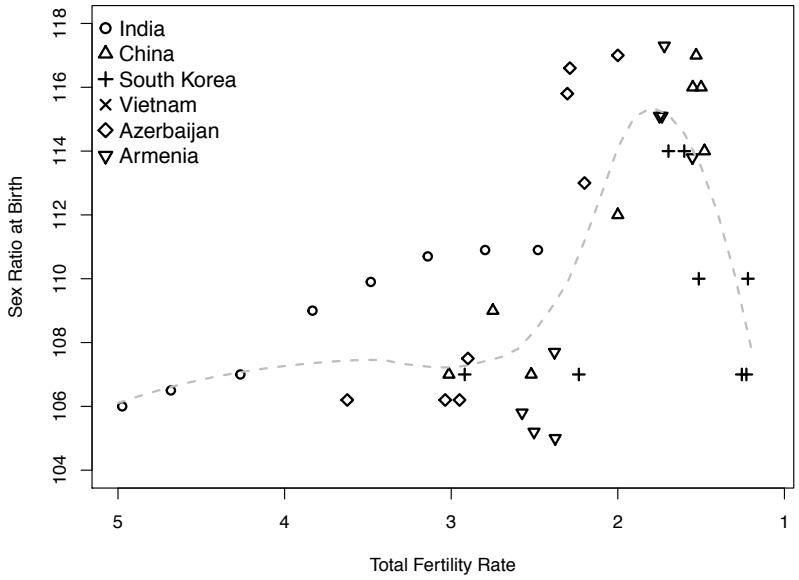


Figure 2.2: Total fertility rate (TFR) and sex ratio (male/female) at birth (SRB), select countries, 1975 to 2015. Data from United Nations (2015a). Grey dashed line shows a locally weighted least squares smoother applied to the data.

two factors – changes in son preference or willingness and the impact of the diffusion of prenatal sex determination technology such as ultrasound – and their interactions with changing fertility norms in explaining the shape and levels of SRB trajectories.

What are the levels and trends of the three micro-level pre-conditions (willingness, ability and readiness) that explain distinct phases of the SRB transition? The plausible levels of these three pre-conditions that inform the shape of the trajectories in these two phases and scenarios for their likely projection into the third phase requires a formalisation of each of the three conditions within a flexible, dynamic model. The microsimulation model enables us to simulate the differing rates of change across each of these dimensions at the individual-level to approximate macro-level trajectories.

2.3 Model Description

2.3.1 Microsimulation and Agent-Based Models

Individual-based simulation techniques—a term used to describe both microsimulation and agent-based modelling approaches—have been used to model demographic processes such as kinship structures and kinship resources (Wachter, 1997; Zagheni, 2011), marriage (Billari et al., 2007; Grow and Van Bavel, 2015) and the transition to parenthood (Aparicio Diaz et al., 2011; Winkler-Dworak et al., 2015). Although both approaches take individuals as the unit of analysis and use computer algorithms (Monte Carlo methods) to determine individual transition between states or the adoption of behavioural rules, the different goals and data requirements of the two simulation approaches have often been used to classify them separately (Zagheni, 2015).

Microsimulation models rely on empirical transition rates and have been predominantly used for predictive purposes. Agent-based models are concerned with showing the emergence of interesting macro-level patterns from the behavioural rules of individual agents. In contrast to microsimulation approaches, agent-based models often tend to model interaction between agents and the environment, adaptation to stimuli and other types of social learning or feedback effects. Despite their different classification, Bijak et al. (2013) and Zagheni (2015) note that the distinction between the two approaches, at least with respect to demographic applications, is not always clear-cut. Agent-based models in demography often include empirical transition rates to model fertility and mortality and microsimulation models often include behavioural rules and feedback mechanisms. The model developed here borrows from both approaches and attempts to show how complex macro-level SRB trajectories can emerge from simple micro-level driving forces for the decision to practice prenatal sex selection, and attempts to indirectly estimate these. The ability to simulate dynamic processes such as

changing rates of son preference or the impact of the fertility decline on increasing readiness to abort, model individual adaptation to exogenous stimuli such as the availability of sex selection technology, explore counterfactual scenarios and overcome data limitations make the simulation approach a particularly useful one for the topic.

2.3.2 State Variables

The model[3] comprises individual agents who each have an identity number (id), age (x), sex (s), cohort (c), son preference (sp), parity (p), sons (so), technology access ($tech$) and abortions (ab). The code is optimised to take advantage of parallel computing using the `snowfall` R package (Knaus, 2013). Table 2.1 lists agent's state variables and their values. The model is initialised as a one-sex model with initial female agents, but then as we model male as well as female births, from the first time-step onward the model becomes two-sex.

An agent's identity number, sex, and cohort are assigned to the agent at birth and remain the same throughout the life course. The variable parity (p) corresponds to the current parity of the female agent. Sons (so) refer to the number of sons she has. Access to technology ($tech$) is a Boolean variable that takes a True or False value depending on whether an agent has access to prenatal sex-determination technology. Abortion (ab) indicates how many sex-selective abortions a female agent has over the course of her life. An agent's age, parity, son preference, sons, access to technology, and abortion values are time-varying and are updated at each time-step in the model.

[3]The model is programmed in R (R Core Team, 2015) and the code and code documentation for the model is available at `http://link.springer.com/article/10.1007/s13524-016-0500-z#MOESM2`.

Table 2.1: Agent's state variables

Agent's state variables	Variable Name	Values
Identity number	id	1, 2, 3, ...
Age	x	0–50
Sex	s	1: female 2: male
Cohort	c	5-year cohort (1930–34, ..., 2005–09)
Son preference	sp	0, 1
Parity	p	0, 1, 2, ...
Sons	so	0, 1, 2, ...
Access to technology	$tech$	1: True 0: False
Abortions	ab	0, 1, 2, ...

2.3.3 Initialisation

To approximate the initial parity distribution of South Korean women from 1980 onwards, we initialised the model 35 years earlier in 1945 to allow all women in reproductive ages (15+) to complete their fertility careers by 1980 and have their children belong to the starting population of 1980. Using UN WPP data, we approximate the South Korean population structure of 1945, and start a simulation in which individuals die and reproduce according to their age-specific death and fertility rates for each year (United Nations, 2013).[4] The abortion procedure is not modelled prior to 1980. The resulting population structure obtained in 1980 is very close to the population structure of South Korea reported in UN WPP, and the minor differences that persist are likely attributable to migration dynamics that are not modelled in our initialisation procedure.

[4]The UN WPP data only offer data from 1950 onwards. Consequently, we approximated the population structure of 1945 with the one from 1950, and for the period 1945–1950 we used the same age-specific fertility rates and death rates as for the period 1950–1955.

2.3.4 Procedures

The model contains two procedures for agents: ageing and reproduction that are carried out at each time-step (or tick) in the model. Each tick corresponds to one year. At each tick an agent ages by one year and time moves forward by one year. The model uses sex- and age-specific mortality rates until age 50 from UN WPP to model ageing (United Nations, 2013). Since we focus on reproductive behaviour, all female and male agents who survive are removed from the simulation at age 50. By simulating male agents until age 50, we can account for child and young adult mortality for males, which may have an impact on a woman's reproductive behaviour as we describe later. This allows us to take into account the mortality feedback effects of son preference. If a woman were to lose her son during his childhood, she might then be able to attempt to have another child.

The reproduction procedure models conception and birth. The risk of childbirth $h_i(x_i, t)$ for each agent i is determined by the age-specific (x_i) fertility rates for that period (t) which are taken from from UN WPP data ($h_i^*(x_i, t)$), her son preference (sp_i), and her current number of sons (so_i) An individual's probability of having son preference is approximated from fertility survey data on measures of stated son preference as described in the following section. The sex of the birth is determined at the point of conception by a probability of 0.5122 for male births and 0.4878 for female births, which corresponds to a biologically normal SRB of 105.[5] We model sex-differential birth stopping behaviour and as our model moves in time and technology becomes available, we model the opportunity for female agents to have sex-selective abortions. Details of how these behaviours are modelled in our agents are described in the next section.

[5]Recent work by Orzack et al. (2015) finds that the natural conception probability is 0.5 but higher female foetal mortality results in the masculine SRB. As we do not explicitly model pregnancies, we model the risk of conception to correspond to the SRB.

2.3.5 Modelling Reproductive Behaviours

Sex Selection: 'Ready, Willing and Able' (RWA)

The model formalises the RWA framework to the practice of prenatal sex selection as presented in Guilmoto (2009). An individual's decision to practice sex selection is the outcome of three processes that are modelled as probabilities, in this order: whether she has a son preference (willing), whether she has access to technology (able) and whether she feels a fertility squeeze to restrict her total family size whilst realising her son preference (ready). Figure 2.3 illustrates how each simulation step proceeds.

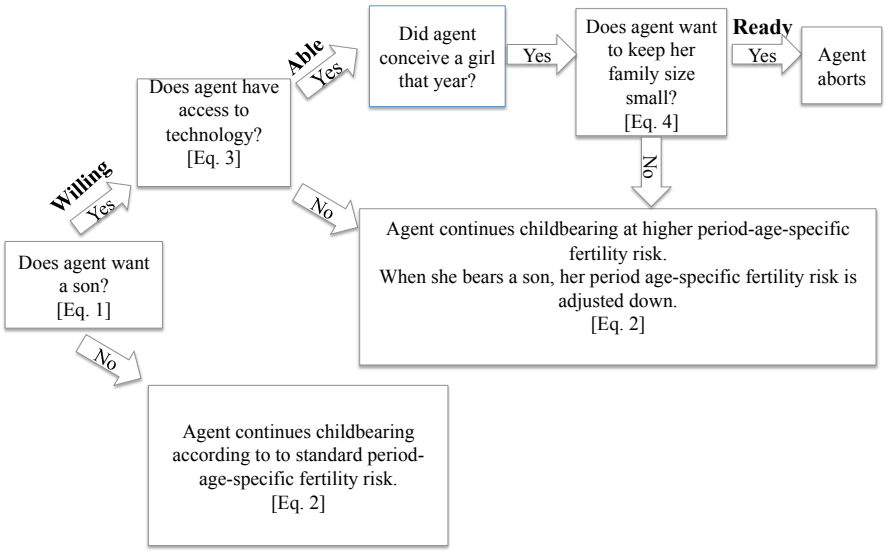


Figure 2.3: Diagram of each simulation step

Son Preference (Willingness)

Son preference (sp_i) is assigned as follows: agents have either no preference for male offspring ($sp_i = 0$) or a desire for one male offspring ($sp_i = 1$). The model is programmed so as to allow an individual's probability to be son preferring

($sp_i = 1$) to be determined by the period (t) as well as cohort (c) she belongs. Only women in their reproductive ages have a son preference. Those who have son preference ($sp_i = 1$) practice differential stopping behaviour, that is, they have higher fertility rates than those who do not or have met their son preference (see the following section on differential stopping behaviour).

For South Korea, we approximate an individual's probability of having son preference as time-varying using data from a question that asks women if they feel they must have a son. This question has been asked in Korean fertility surveys carried out by the Korean Institute for Health and Social Affairs. We rely on time trends in proportions stating they must have a son reported in Chung and Das Gupta (2007b). As we are modelling a dichotomous proportion that is bounded between 0 and 1, we fit a logistic regression (Eq. (2.1)) with one predictor variable (δ_t) and an intercept term (δ_0) to obtain yearly probabilities of son preference for the period between 1980 and 2050.

$$sp(t) = \frac{e^{\delta_0+\delta_t}}{1 + e^{\delta_0+\delta_t}} \tag{2.1}$$

Figure 2.4 shows the observed and fitted son preference trends from Eq. (2.1). If cohort-disaggregated data are available an additional coefficient capturing a cohort effect would need to be estimated in Eq. (2.1) since the model is generally programmed to allow son preference to be assigned by period and cohort characteristics of the female agent. For the South Korean case, we were unable to access the survey micro-data to generate cohort-disaggregated son preference measures. Thus, whether a woman in her reproductive age has a son preference in a particular year is determined by the period probability, which is assumed to be constant across cohorts. For the South Korean case, Chung and Das Gupta (2007b) note that period effects were stronger than cohort effects in the decline of stated son preference in South Korea.

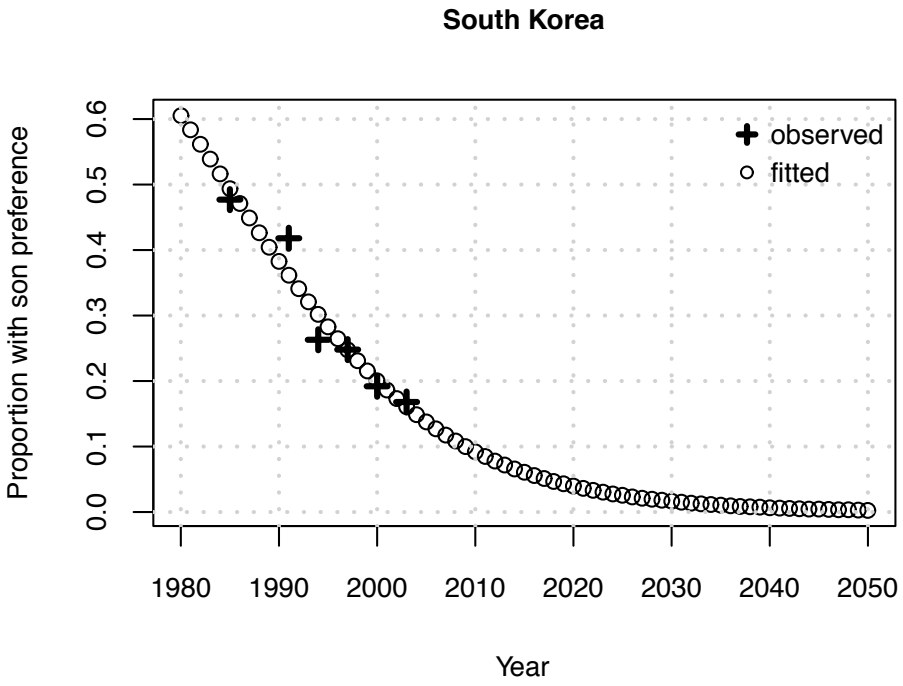


Figure 2.4: Proportion with son preference, South Korea 1980–2050, observed values from Chung and Das Gupta (2007b)

We choose to assign son preference dichotomously because we believe this effectively captures the way the social norm influences reproductive behaviour and allows for easy interpretation for how much son preference exists in a population. While some individuals, particularly among older cohorts, may desire more than one son, the desire for several sons likely reflects the indirect influence of higher mortality conditions where bearing at least two sons might be considered a strategy to ensure at least one survived into adulthood (Cain, 1993). By simulating mortality dynamics for males until age 50 this feedback effect of high mortality levels on fertility behaviour is accounted for in the model as mentioned in the earlier section on Procedures.

Differential Stopping Behaviour

Differential stopping behaviour (DSB) is a common manifestation of son preference (Arnold et al., 1998; Larsen et al., 1998; Retherford and Roy, 2003). In the model, female agents with unmet son preference have a higher fertility risk, expressed as a deviation from the standard fertility schedule $h_i^*(x_i, t)$ by a proportional expansion factor $(1 + \gamma)$.

$$h_i(x_i, t) = \begin{cases} h^*(x_i, t) & \text{if } sp_i(t) = 0, \\ h^*(x_i, t) \times (1 + \gamma) & \text{if } so_i(t) < sp_i(t), \\ h^*(x_i, t) \times (1 - \alpha) & \text{if } so_i(t) \geq sp_i(t) \text{ and } sp_i(t) \neq 0. \end{cases} \tag{2.2}$$

As Eq. (2.2) shows, if the current number of sons $so_i(t)$ of female agent i is less than her son preference $sp_i(t)$, her period age-specific rate is multiplied by a factor of $(1 + \gamma)$ where γ may be conceptualised as a son preference intensity parameter. For example, $\gamma = 0.2$ implies that a woman with unmet son preference experiences a fertility risk that is 20 % higher than the period age-specific schedule that normally determines her risk for childbearing. A higher value of γ indicates a higher intensity of son preference through its impact on fertility behaviour.

When son-preferring female agents bear a son, their birth risk is adjusted down by a factor of $(1 - \alpha)$, indicating a reduced risk from the standard fertility schedule $h_i^*(x_i, t)$. Standard period age-specific rates $h^*(x_i, t)$ apply to female agents with no son preference ($sp = 0$).

Access to Technology (Ability)

We use the logistic diffusion model, widely used to describe the diffusion of new technologies, to model an individual's ability or probability of gaining access to prenatal sex-determination technology (Geroski, 2000).

$$Ability(t) = \frac{e^{\rho\,(t-\phi)}}{1 + e^{\rho\,(t-\phi)}}. \tag{2.3}$$

In Eq. (2.3) $Ability(t)$ simulates an individual's probability of getting access to technology, which increases as a function of time (t), where t corresponds to the time-step in the simulation ($t = 0, 1, 2, ..., 30$ for a 30-year simulation covering a period of 1980–2010), ρ determines the slope or rate of increase, and ϕ the inflection point of the logistic diffusion curve. At the population level, $Ability(t)$ can be interpreted as the proportion of individuals at a particular time-step gaining access to prenatal sex-determination technology. At each time-step $Ability(t)$ gets recalculated, and a random number from a uniform distribution for each individual is redrawn, which when less than $Ability(t)$ sets the state variable $tech_i(t) =$ True for that individual.

We model the availability of prenatal sex determination technology as a population-level diffusion process. Although this is not explicitly modelled here, different forms of heterogeneity in ultrasound access could of course be implicit in the diffusion process. One form of this heterogeneity may be regional heterogeneity – particularly in countries such as India and China that have vast inequalities in wealth across regions. Indeed, Chen et al. (2013) reported that there was significant variations by region in the diffusion process of ultrasound in China. Similarly in India, regional disparities in development and prenatal and maternal care (Pathak et al., 2010) and ultrasound use have been documented Akbulut-Yuksel and Rosenblum (2012). Southern, northwestern and northern states generally appeared to have more widespread access to ultrasound for prenatal care than

states of the northeast, east and central India, as reported in the District Level Health Survey (DLHS) that asked respondents about ultrasound use in their last pregnancy. In contrast, in wealthier, developed contexts such as South Korea, the diffusion of technology may be a relatively swift across regions, even though an urban to rural diffusion process may nevertheless exist (Park and Cho, 1995). An additional source of heterogeneity may be that across different socio-economic groups in the population. Diffusion processes are often characterised by the early uptake of the technology by pioneer groups, such as the wealthier, more educated groups followed by the eventual uptake of the technology among wider groups as the technology becomes more widely available. This mechanism of wider ultrasound availability and uptake amongst the better off has been used to explain why SRBs have often been the most distorted amongst educated and wealthier mothers (Guilmoto, 2015; Jha et al., 2011; Bhat and Zavier, 2007).

Fertility Decline (Readiness)

As fertility falls, norms surrounding smaller families become more entrenched. Individuals are likely to desire smaller families and if means are available to allow them to realise their son preference with small family size, they are likely to do so. This is the motivating idea to generate an individual's probability (readiness) to abort. Guilmoto (2009) describes the readiness to abort as strongly related to the fertility squeeze felt by couples planning the size and composition of their families. This fertility squeeze can be conceptualised as a form of social pressure that is closely related to prevailing total fertility levels and determines an individual's readiness to abort. This readiness to abort is likely higher when fertility levels are lower and couples feel a greater squeeze or pressure to reconcile their son preference at lower parities than when average family size is higher and proceeding to higher parities is not out of step with prevailing total fertility norms.

Equation (2.4) shows how we model readiness to sex-selectively abort. An individual is only ready if she has unmet son preference (willing) and she has access to technology (able), that is, if $sp_i(t) > so_i(t)$ and $tech_i(t) = \text{True}$. Hence, if these two conditions are met,

$$Readiness_i(t) = \begin{cases} \min\left\{1, \frac{\beta}{\text{TFR}(t-1)}\right\} & \text{if } p_i(t) = 0, \\ \\ \min\left\{1, \frac{p_i(t) \times \sigma}{\text{TFR}(t-1)}\right\} & \text{if } p_i(t) > 0, \end{cases} \tag{2.4}$$

where $p_i(t)$ denotes the parity of agent i at time t. Since $Readiness_i(t)$ is a probability to abort, it is bounded between 0 and 1.

An agent's readiness to abort depends on her current parity ($p_i(t)$) at the beginning of the period, prevailing, model-generated[6] fertility levels, $\text{TFR}(t-1)$, and two parameters σ (if $p_i(t) > 0$) and β (if $p_i(t) = 0$).[7] In Eq. (2.4), the ratio of the agent's current parity and prevailing fertility levels is conceptualised as determining the extent of her fertility squeeze. When fertility levels are higher, for example at 3, a woman with unmet son preference and access to technology has a $0.33 \times \sigma$ probability to abort as she transitions from first to second parity compared with a woman who transitions from first to second parity when total fertility levels have fallen to 2.5 and the probability is $0.4 \times \sigma$. The parameter σ allows us to assess the impact of the fertility squeeze by scaling it up or down on SRB trajectories when calibrating the model; it also allows to account for the possibility that even if the fertility squeeze may be present in a population, there might be other counteracting forces such as religious or cultural taboos against the practice of abortion (Hessini, 2007), or punitive measures against sex-selective

[6] Although period age-specific fertility rates are an input in the model, they are modified by the son preference intensity (γ) and reduction (α) parameters, as well as the proportion of the population with son preference in that year, which result in deviations from the fertility schedule as defined in Eq. (2.2).

[7] Since an agent's current parity is determined at the beginning of the period t and TFR is calculated at the end of the period t, the most recently observed TFR with respect to an agent's parity when she is at risk of childbearing in that period is $\text{TFR}(t-1)$.

abortion that may not allow for the full extent of the fertility squeeze to be felt (Ganatra, 2008). Conversely, higher σ values indicate a greater intensity of the fertility squeeze.

Table 2.2: Simulation model parameters

Category	Parameter	Range	Description
Son preference ('willingness')	γ	$[0, 1]$	Son preference intensity
	α	$[0, 1]$	Birth risk adjustment (when son preference realized)
Fertility decline ('readiness')	σ	$[0, 2.5]$	Fertility squeeze scaling factor for parity 1 and higher
	β	$[0, 0.5]$	Fertility squeeze scaling factor for parity 0
Access to technology ('ability')	ρ	$[0, 2]$	Rate of technology diffusion
	ϕ	$[0, 20]$	Inflection point for technology availability

Indeed, in some situations, particularly as fertility becomes very low, we may expect some individuals to abort at the lowest possible parity—parity 0 or before the transition to first birth. Although abortions before the first birth may become more frequent as fertility falls, these tend to be rarer events than higher parity abortions (Guilmoto, 2009, p. 533). We therefore model parity 0 abortions as a function of prevailing fertility levels but subject to their own parameter β than higher parity abortions, which are controlled by the parameter σ. Table 2.2 lists the relevant parameters that control the three factors—son preference, fertility decline and technology availability—in the model. The range listed in the table refers to theoretically plausible values for each parameter over which we analyse model behaviour.

Chapter 3

The Dynamics of Son Preference, Technology Diffusion and Fertility Decline Underlying Sex Ratio at Birth Distortions in South Korea

3.1 Overview

This chapter presents the calibration for South Korea of the ready, willing and able (RWA) simulation model described in the previous chapter. SRB distortions emerged in the early 1980s in South Korea.[1] By the 1990s South Korean SRBs started to level off and very soon afterwards by the mid-1990s SRBs showed a remarkable turnaround towards normalisation. By the mid-2000s SRBs had already returned to near-normal levels. As the only country that has been through all three stages of the archetypal "sex ratio transition", calibrating the model to the South Korean case can shed light on the levels and rates of change in son preference, diffusion of sex-selective abortion technology and probabilities of sex-selective abortion that plausibly underpinned different stages of the transition.

[1] Materials from this chapter have been published in Kashyap, Ridhi, and Francisco Villavicencio. "The Dynamics of Son Preference, Technology Diffusion, and Fertility Decline Underlying Distorted Sex Ratios at Birth: A Simulation Approach." *Demography* 53.5 (2016): 1261-1281.

The calibration exercise reveals a number of interesting insights about the micro-level underpinnings of SRB trajectories. The simulations show that even as proportions of the population with son preference declined in South Korea from around 45 % in the mid-1980s to around 25 % in the mid-1990s, South Korean SRBs became distorted. SRBs peaked in the 1990s when the proportion wanting a son in the South Korean population was ∼30 %. The SRB distortion, the model suggests, was likely caused by an early and steady increase in access to prenatal sex-determination technology over the 1980s combined with growing propensities to sex-selectively abort at low parities as fertility declined. Further in this chapter I examine experimental scenarios with the model to see how SRB trajectories emerge if assumptions about changes in son preference and the readiness to abort are modified. This is followed by model sensitivity analysis to systematically assess which parameters influence model outcomes most. This exercise suggests that the shape of SRB trajectories in South Korea were very sensitive to the timing of the onset of technology as well as the rate of technology diffusion. Peak levels reached by SRB trajectories were very sensitive to increases in the readiness to abort at low parities triggered by declining fertility. Simulations suggest that the impact of sex-selective abortion on fertility levels in South Korea was relatively small. Sex-selective abortion likely reduced fertility levels by 2.5–3 % in the end of the 1980s and early 1990s as SRBs peaked.

3.2 Simulation Results

3.2.1 Model Calibration for South Korea

We calibrate the model for South Korea by seeking to match the shape and levels of model-generated SRB trajectories with UN WPP estimates of the same for the period between 1980 and 2010 (United Nations, 2013). We find the combination of parameters that minimise the average yearly error (model fit measure, or root

mean squared error (RMSE)) between the simulated SRB trajectories and UN estimates of South Korean SRBs. The model fit measure can be expressed as:

$$\text{Model Fit or RMSE} = \sqrt{\frac{\sum\big(\text{UN SRB}(t) - \text{Simulated SRB}(t)\big)^2}{2010 - 1980}} \tag{3.1}$$

Low values of the RMSE model fit measure indicate better fit with smaller average yearly errors between model-generated SRBs and UN SRB estimates. We also attempt to calibrate model-generated TFR levels to UN WPP estimates of the same, since the model-generated TFR forms an important part of the readiness condition as shown in Eq. (2.4) in Chapter 2.

Our calibration strategy proceeds as follows: we run the model on an exploratory Latin Hypercube sample comprising 224 design points. One simulation was run at 180 of the 224 design points, and 5 repetitions were performed at 44 randomly-chosen points in the sample, totalling 400 simulation runs ($180 \times 1 + 44 \times 5$). Latin Hypercube samples have good space-filling properties, perform better than random samples in assessing model behaviour in a comparatively small number of runs, and are recommended good practice in the literature on the design of computer experiments (Santner et al., 2003). Each design point corresponds to a unique combination of the six model parameters. These design points range over the minimum and maximum values for the parameters listed in Table 2.2. From this sample of points, we interpolate across all possible combinations of the parameter space (a total of 548,856 design points) using a regression metamodel, explore the sensitivity of the model to different parameters and to different regions of the parameter space to find those that give good fit (more details in section on Sensitivity Analysis and in Appendix to this chapter). Regions where the simulated SRB trajectories match UN estimates for South Korea well (with low model fit or RMSE values) indicate early (low ϕ) and

steady technology diffusion (ρ values between 0.5 to 0.6), and a strong readiness to abort (σ values upwards of 1.7 combined with smaller values of β in the region of 0.2). SRB fit is expectedly less sensitive to α and γ, which impact fertility levels more than SRBs directly. We run the simulation at a combination of levels varying the ability and readiness parameters, as shown in Fig 3.1. In Fig. 3.1 panel (a) we vary ability parameters ρ and ϕ across their range whilst holding $\sigma = 1.7$ and $\beta = 0.2$, and in panel (b) we vary readiness parameters σ and β whilst holding $\rho = 0.5$ and $\phi = 7$.

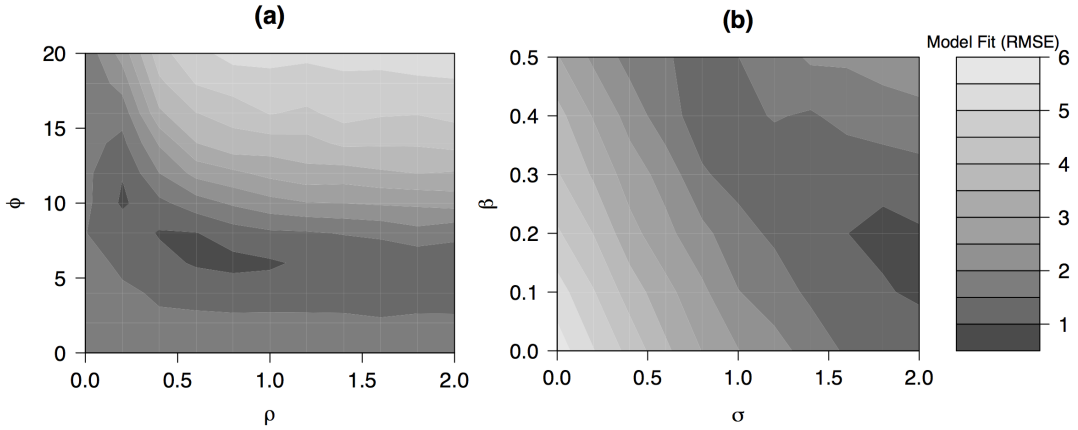


Figure 3.1: Model fit measure or root mean squared error (Eq. (3.1)) in response to: panel (a) varying ability parameters (ρ and ϕ), (b) varying readiness parameters (σ and β). Lower values indicate better fit between simulated and UN SRB estimates

Data on son preference from South Korean fertility surveys indicate stated son preference declined from 48 % in 1985 to 26 % in 1994; over the same time South Korean SRBs rose from around 108 to 114 and fertility declined around 2.1 to 1.6. It is interesting to note that son preference levels appear to be relatively low ($\sim$30 % of the population stating must have son) as SRBs reached their peak in 1990.

Figure 3.2 shows model-generated SRB and fertility trajectories with 95 % empirical confidence interval bands that best match UN WPP SRB trajectories, which are shown in the background in grey.[2]

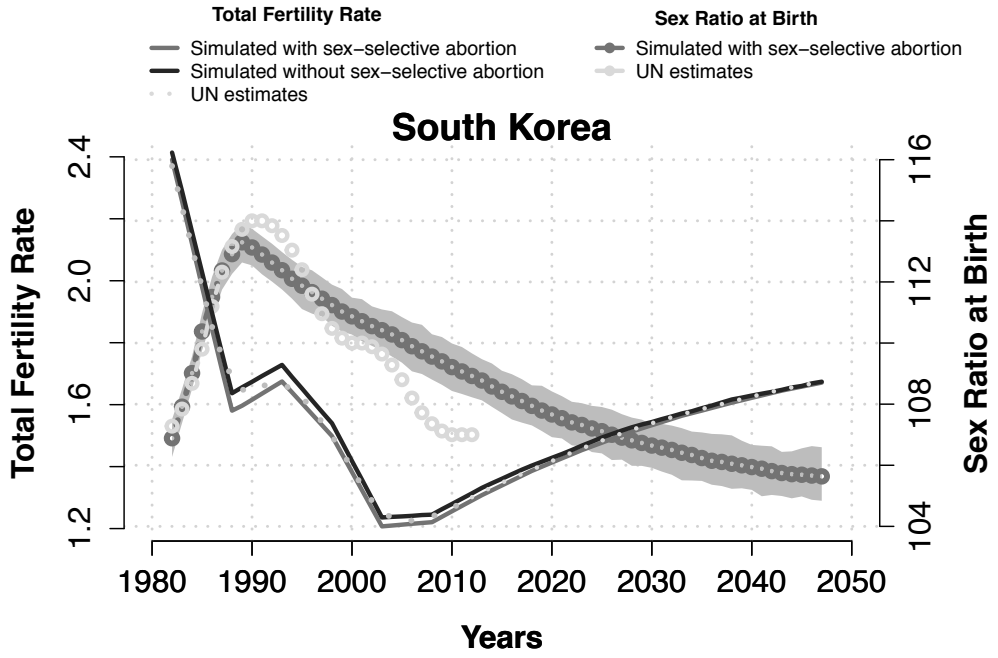


Figure 3.2: Simulated total fertility rate (TFR) and sex ratio at birth (SRB) trajectories, 5-year moving averages, South Korea, 1980–2050. Grey band indicates 95 % empirical confidence interval of simulated SRB trajectories

The dotted-dashed SRB curve in Fig. 3.2 shows 5-year moving averages of SRBs averaged across 240 simulation runs with an initial population of 1,000,000 individuals, with the following parameter values: $\gamma = 0.20, \alpha = 0.075, \rho = 0.5, \phi = 7, \sigma = 1.7$ and $\beta = 0.2$. Increasing β to levels closer to 0.25 allows us to match the peak better but at the expense of worsening the fit for the period 1998 onwards thereby worsening the average yearly error between the simulated and UN SRB estimates. Our simulated fit, while capturing the general shape and

[2]UN SRB and fertility trends are issued for five-year periods (1970–75, 1980–85, etc.). Our model runs produce yearly estimates. To enable a better comparison between the UN estimates and our simulated results, we present smoothed UN estimates, in which we linearly interpolate the five-year values for each year. For this, as advised in UN metadata, we assume the value for each of the five-year intervals corresponds to mid-point within the interval (e.g. 1970–75 rate corresponds to mid-point 1973).

SRB levels well, does not capture the drastic turnaround towards normalisation that occurred in the mid-2000s.

The dynamic trajectories and associated parameters of willingness (son preference), ability (technology access) and readiness (abortion probabilities as a function of the fertility squeeze) that underlie the simulated SRB curve reported in Fig. 3.2 are shown in Fig. 3.3. The technological diffusion trajectories indicate widespread availability of prenatal sex determination technology by the mid-1990s with the steepest rise in the 1980s combined with an increase in the probabilities to abort in the mid-1980s that lead to the rise in the SRB, even as son preference continues to decline throughout the period.

A son preference intensity parameter value of $\gamma = 0.20$ and birth risk adjustment parameter value of $\alpha = 0.075$ allow us to match Korean fertility trajectories over the period with the prevailing levels of son preference very well. How much did the practice of sex-selective abortion hasten the fertility decline in South Korea? To answer this question, we adopted a counterfactual strategy assuming no sex-selective abortion was practiced ($\sigma = 0$ and $\beta = 0$) keeping all other parameters constant at the levels used to generate the distorted SRB trajectories reported in Fig. 3.2. The solid black line shows TFR levels assuming no sex-selective abortion had been practiced. When SRBs peaked at the end of the 1980s and early 1990s, the TFR levels in the no sex-selective abortion scenario are about 2.5–3 % higher than with sex-selective abortion.

3.2.2 Experimental Scenarios

We present two sets of counterfactual scenarios to show how SRB trajectories respond to different assumptions about willingness, readiness and ability. First, we compare how SRB trajectories would have looked had son preference ('willingness') been constant at (1) 1980 levels of 50 %, and (2) at 100 % with son preference. We keep technology diffusion early and steady at the same parameters

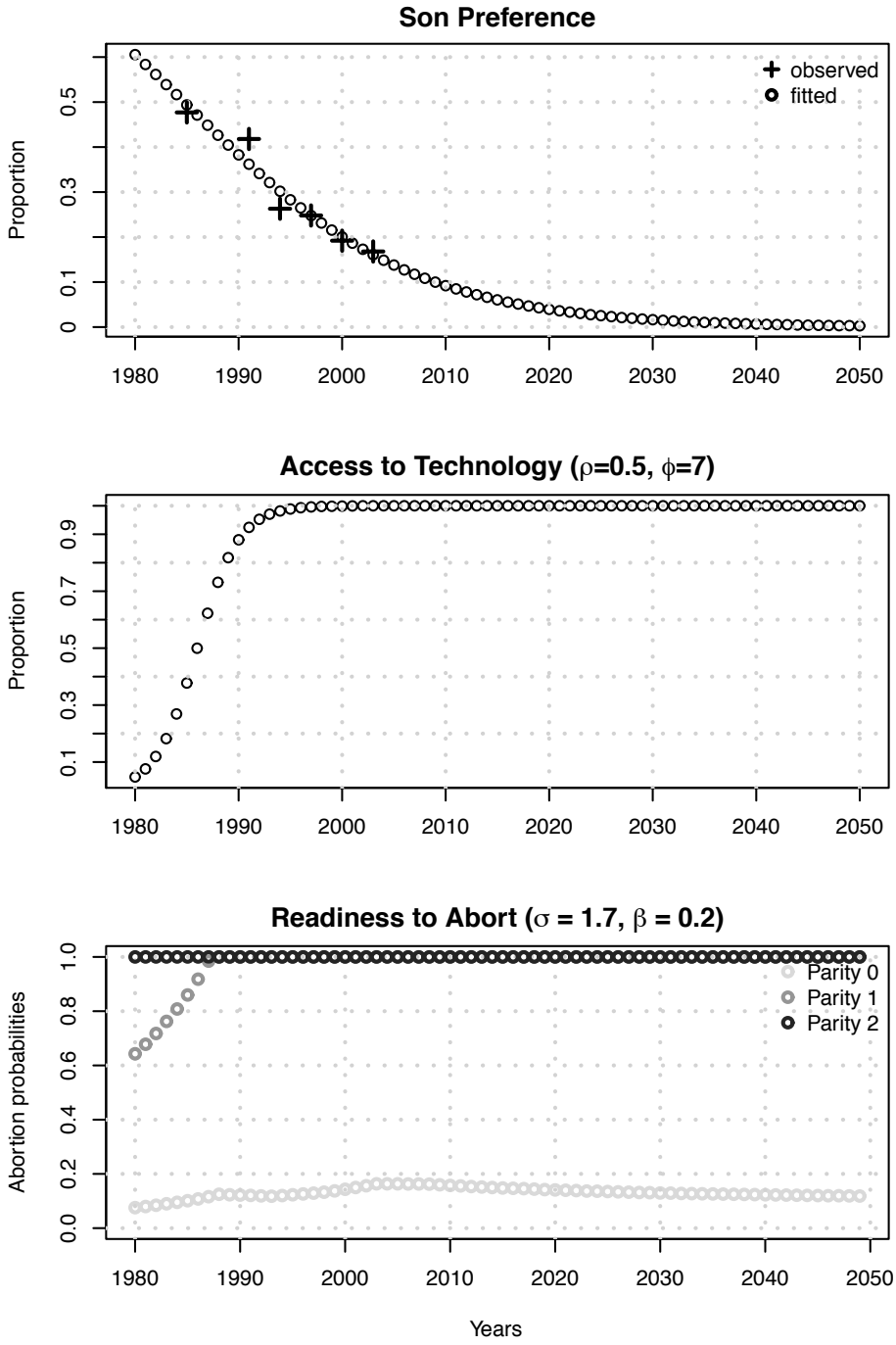


Figure 3.3: Son preference (willingness), access to technology (ability) and parity-specific abortion probabilities (readiness) over time, 1980–2050, for South Korea underlying calibrated model

as in Fig. 3.2 before ($\phi = 7$ and $\rho = 0.5$) along with strong readiness parameters of $\sigma = 1.7$ and $\beta = 0.2$. We compare these against the simulated SRB trajectories presented in Fig. 3.2. All three SRB trajectories are shown in Fig. 3.4.[3]

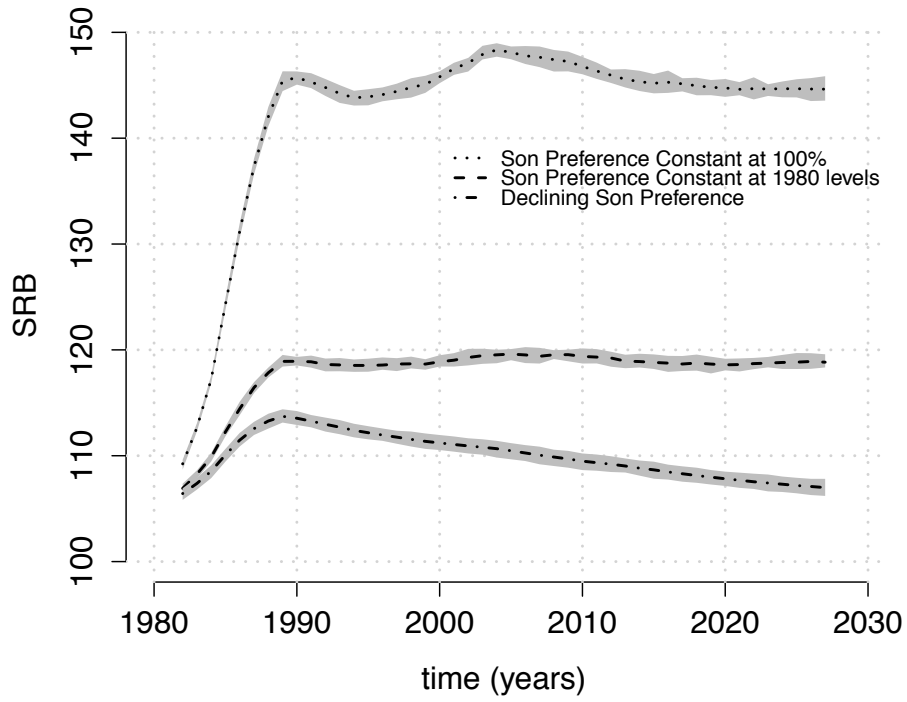


Figure 3.4: Simulated sex ratio at birth (SRB) trajectories, 5-year moving averages, over 50 years assuming son preference remains constant at 1980 levels (50 %) and 100 %. Comparison with simulated SRB trajectories shown in Fig. 3.2. Grey band indicates 90 % confidence interval

In both constant scenarios, SRB trajectories stabilise at high levels by the early 1990s and do not show a turnaround. If son preference is kept at 1980 levels SRBs stabilise at levels of 120, and in the 100 % scenario they stabilise at very high levels of 145—levels that have not been observed in national-level SRB trajectories anywhere.

In the second set of scenarios we modify assumptions about ability and readiness. These are shown in Fig. 3.5, which assumes: (1) technology availability stays constant at 50 % throughout the simulation ($\rho = 0$ and $\phi = 0$, and $\sigma = 1.7$ and $\beta = 0.2$), and (2) the fertility squeeze felt by individuals is less intense leading

[3]In all experimental scenarios, we start with an initial population of 500,000 and repeat the simulation 36 times.

to a lower readiness to abort with no parity-0 abortion (σ is reduced to 1 instead of 1.7 in Fig. 3.2 and β is reduced to 0 instead of 0.2, with $\rho = 0.5$ and $\phi = 7$). In scenario (1), SRB rise is triggered by increasing readiness to abort induced by the fertility squeeze but SRB levels start high already in 1980 and don't capture the shape between 1980 and 1990 well. In scenario (2), SRB levels remain much lower reaching a peak of 110 instead of 113–114 when σ and β are higher in the best fit simulated trajectories.

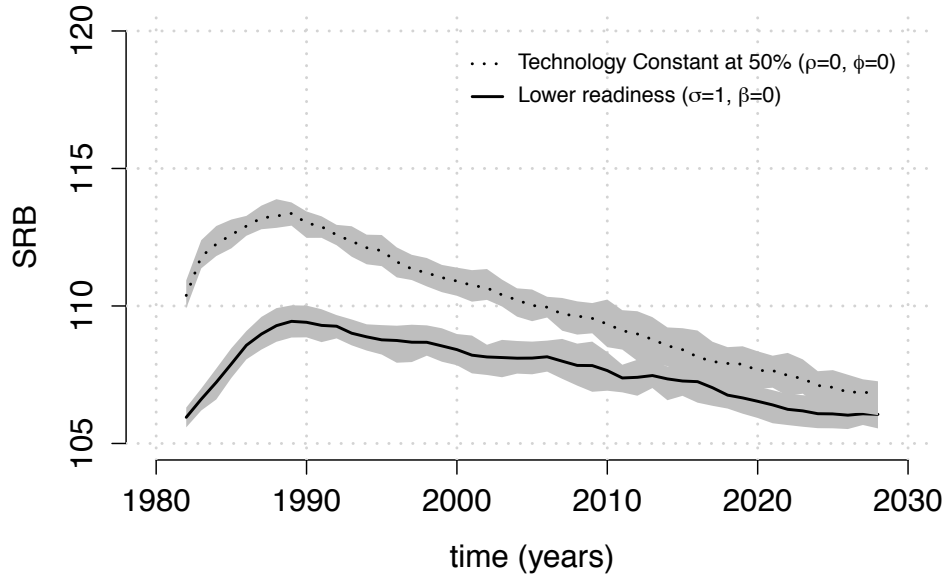


Figure 3.5: Simulated sex ratio at birth (SRB) trajectories, 5-year moving averages, over 50 years assuming (1) technology availability stays constant at 50 % throughout the simulation period, (2) fertility squeeze is less intense with readiness parameters $\sigma = 1$ and $\beta = 0$. Grey band indicates 90 % confidence interval

3.2.3 Sensitivity Analysis

How much of the variance of model outcomes is accounted for by different parameters? We address this issue by sensitivity analysis of three model outcomes: (1) the model fit or RMSE measure, which is the average yearly error for 1980 to 2010 between simulated and UN estimates of South Korean SRB trajectories (see

Eq. (3.1)); (2) the South Korean SRB for 1990, when the SRB peaks according to UN estimates; and (3) the maximum SRB level reached by the model. We estimate regression metamodels on data generated by the simulation model.[4] These models separately take each of the three outcomes of interest as the dependent variable, with the parameter values as the predictor variables in the regression model. Regression meta-modelling for simulation models is widely used in the sensitivity analysis of simulation models (Santner et al., 2003; Kleijnen, 1995) and has been used in agent-based modelling applications in demography (Grow and Van Bavel, 2015). After finding a well-fitted metamodel for each outcome, we perform an analysis of variance (ANOVA) of the regression metamodel to assess how much of the model variance is accounted for by each parameter (Santner et al., 2003, Ch. 7). The variance explained by each parameter as well as selected, statistically significant ($p < 0.05$) higher-order terms and interactions from the ANOVA-decompositions are reported in Table 3.1. Further sensitivity analysis results that compare the regression metamodels to other approaches such as Gaussian process emulators are reported in the Appendix to this chapter.

Nearly half of the variance (44.3 %) in the model fit or RMSE measure can be accounted for by the inflection point for the onset of technology diffusion (ϕ), the quadratic term involving the speed of technology diffusion (ρ), and the interaction of the two technology diffusion parameters. This indicates that the shape of the South Korean SRB trajectory, including the rise and and turnaround, is especially sensitive to the ability parameters. The interaction terms involving the readiness parameters (σ and β) account for 8 % of the variance, and interaction terms involving γ, the son preference intensity parameter, account for $\sim$7 % of the variance of the model fit measure. Technology diffusion parameters also account for the greatest fraction of the variation in the levels of the South Korean SRB

[4] As described previously, we use a Latin Hypercube Sample consisting of 224 design points with 5 repetitions at 44 of those points totalling a dataset of 400 observations that covers different parameter combination across the minimum and maximum theoretical values of the parameter ranges.

Table 3.1: Proportion of variance (%) of three model outcomes: (1) model fit measure, (2) SRB 1990, (3) maximum SRB attributable to model parameters and their interactions. Variance measures derived from analysis of variance (ANOVA) of regression metamodels

(1) Model fit measure		(2) SRB 1990		(3) Maximum SRB	
Parameter	Variance	Parameter	Variance	Parameter	Variance
α	1.54 %	α	0.34 %	α	0.00 %
γ	0.50 %	γ	3.09 %	γ	14.30 %
σ	0.30 %	σ	9.75 %	σ	28.28 %
β	0.40 %	β	12.93 %	β	20.24 %
ϕ	26.40 %	ϕ	29.70 %	ϕ	4.93 %
ρ	2.50 %	ρ	5.53 %	ρ	0.50 %
Higher order terms		Higher order terms		Higher order terms	
ρ^2	5.40 %	ρ^2	9.14 %	ρ^2	1.65 %
σ^2	2.60 %	σ^2	3.23 %		
γ^2	1.11 %	γ^2	1.45 %		
Significant interactions		Significant interactions		Significant interactions	
$\phi * \rho$	14.50 %	$\phi * \rho$	2.05 %	$\sigma * \phi$	1.17 %
$\sigma * \phi$	2.30 %	$\sigma * \phi$	2.65 %	$\beta * \phi$	0.67 %
$\beta * \rho^2$	2.30 %	$\gamma * \phi$	1.45 %	$\gamma * \sigma$	0.90 %
$\sigma * \beta$	8.00 %	$\sigma * \phi * \rho$	1.67 %		
$\gamma * \sigma$	4.50 %				
$\gamma * \beta$	2.35 %				
Residuals	22.06 %	Residuals	12.98 %	Residuals	20.89 %

in 1990 ($\sim$47 % including first-, second-order and interaction terms), followed by the readiness parameters of β and σ, which account for $\sim$26 %. The maximum SRB levels reached in the model is most sensitive to the readiness parameters (σ and β), which together account for nearly 50 % of the variation in this outcome. The son preference intensity parameter γ also accounts for a sizeable proportion of the variation in the maximum SRB outcome, although it is more important in its role in interactions with other parameters for the other two outcomes. This is plausible since the effect of α and γ are not directly on the SRB but mediated through the TFR in the model.

The regression metamodels incorporating linear, quadratic and interaction terms for each of the three outcomes capture a sufficiently high fraction of the variance in the output. For the model fit measure, the best-fit metamodel captures 78 % of the model variance (residual variance 22.06 %). The best-fit regression metamodel with the maximum SRB reached in the model as the outcome captures a similar proportion of the variance (79.11 %; residual variance 20.89 %), whereas the metamodel with the South Korean SRB in 1990 captures 87.02 % of the variance (residual variance 12.98 %).[5]

3.3 Discussion

What balance of micro-level behaviours underlie different stages of the sex ratio at birth (SRB) transition at the macro-level? What will be the future course of SRB trajectories? By formalising a general framework for the decision to practice prenatal sex selection—ready, willing and able—at the individual level, the goal of this study has been to present a model that can be fitted at the individual-level to approximate how changes in son preference (willingness), technology diffusion (ability) and the fertility squeeze triggered by the fertility decline (readiness) generate macro-level SRB trajectories. The model reveals a number of interesting insights on the micro-dynamics that underpin the sex ratio transition. Even low levels of son preference can cause significant SRB distortions when technology diffuses steadily and fertility falls fast. The shape of South Korean SRB trajectories between 1980 and 2010 —including the steep rise and turnaround—was particularly sensitive to the inflection point for technology diffusion (ϕ) followed by the rate of technology diffusion (ρ). The maximum SRB levels were highly sensitive to the readiness to abort, controlled by σ and β which jointly accounted

[5]For all three outcomes, higher-order polynomial terms beyond quadratic terms did not account for a statistically significant fraction of the variance and were not included in the models. The residual variance term captures, in part, simulation stochasticity along with other variation that cannot be captured by the metamodel.

for nearly 50 % of the variation in the maximum level reached. At peak SRB levels in the 1990s in South Korea, we estimate that sex-selective abortion likely reduced fertility levels only slightly by 2.5–3 %.

The simulation model presented here provides a sufficiently general and useful approach that can be adapted to different contexts. The experimental scenarios demonstrate that the model is capable of generating SRB trajectories of different peak levels and shapes from different parameter combinations of the three common underlying processes. In other contexts, such as China where SRBs have peaked at levels higher than South Korea's, we would likely need higher values of the readiness parameters σ and β than in South Korea due to the intensified fertility squeeze triggered by the one child policy (Li et al., 2011; Zhu et al., 2009), combined with a slightly later and more heterogeneous ultrasound diffusion than that in South Korea (Chen et al., 2013). In the next chapter, we consider Indian SRB trajectories, which have shown a more gradual increase and have yet to show a clear turnaround like the South Korean case.

Appendix

Appendix 3.A Model Sensitivity Analysis

3.A.1 Overview

The goal of sensitivity analysis with the model is to assess how much of the model variance for three model outcomes can be accounted for by different parameters and their interactions. The three outcomes we are interested in are:

1. the model fit measure (or the root mean squared error, RMSE) that denotes the average error for each year between 1980 and 2010 between the simulated sex ratio at birth (SRB) and UN estimates of SRB. This can be expressed as:

$$\text{Model Fit or RMSE} = \sqrt{\frac{\sum\big(\text{UN SRB}(t) - \text{Simulated SRB}(t)\big)^2}{2010 - 1980}} \tag{3.2}$$

2. the South Korean SRB in 1990;

3. the maximum SRB level attained by the model.

Running the model at all-possible combinations of the six parameters is computationally expensive. In order to minimise running time, whilst obtaining a robust understanding of model behaviour, metamodelling approaches are widely used in the literature in the theory and design of computer experiments (Santner

et al., 2003; Kleijnen, 1995). A metamodel fits a model to the experimental data generated from the simulation model. We use two classes of metamodels: 1) regression metamodels; 2) Gaussian process emulators. For our simulation model, both approaches provide similar results in terms of highlighting which parameters are influential for each of the three model outcomes of interest. Given the good fit provided by both methods (see cross-validation below), and the similarities in the sensitivity analysis results, we draw on Grow (2017) who recommends the use of regression metamodels for simulation approaches as these are widely used by and understood by social scientists. Consequently, we report results from the regression-based analysis of variance in the main analysis presented in the chapter.

3.A.2 Experimental Design

For sensitivity analysis of the model across the minimum and maximum theoretically plausible range of the parameter values (see Table 2.2 in the chapter), we run the model at 224 points of a maximim-distance latin hypercube sample (LHS). We repeat the simulation 5 times at a randomly-chosen subset of 44 of these points resulting in a total sample of 400 points. LHS designs have good space-filling properties, perform better than random samples, and have been shown to perform well with regression metamodels (Santner et al. 2003, 158) as well as Gaussian process emulators (Kennedy and O'Hagan, 2001). According to standard practice in the literature, we standardise each input parameter to between 0 and 1 to enable comparability for coefficients.

3.A.3 Regression Metamodel

Table A.3.1 reports the coefficients from the best fit regression metamodel for the three outcomes of interest from the simulation. Incorporating higher order (above quadratic terms) does not improve model fit. For each of the three out-

comes, the R-squared and adjusted R-squared values indicate a robust fit (above 75% in each case) to enable sensitivity analysis conclusions on the basis of the regression metamodel. These regression metamodels highlight how the measure of model fit, the mean SRB in 1990 and the mean maximum SRB respond to different parameters in the simulation. A higher value of the model fit measure indicates worse fit between the simulated and UN estimates of SRBs. The negative signs on the coefficients in the column model fit measure in Table A.3.1 indicate that higher values of σ, β (the readiness to abort parameters for parity 1+ and parity 0 respectively) improve model fit for South Korea. As expected, these models highlight that higher values of the readiness to abort parameters predict increased SRB in 1990 as well as maximum SRB levels in the simulation model. SRB levels, in 1990 and the maximum levels attained by the model, are lower with slower rates of technology diffusion, ρ, and show a negative quadratic shape with ϕ, the inflection point for technology diffusion. The analysis of variance (ANOVA) quantifying how the variance in model output is attributable to different parameters are summarised in Table 3.1 in the main text of the chapter.

3.A.4 Gaussian Process Emulators

In addition to the regression metamodel, we also fit a Gaussian process emulator, a flexible class of metamodels developed for the statistical analysis of computer models, to perform sensitivity analysis. Bijak et al. (2013) apply Gaussian process emulators to a re-implementation of one of the most well-known applications of agent-based modelling in demography, the 'wedding ring' model for marriage developed by Billari et al. (2007). The statistical theory for emulation is outlined in Kennedy and O'Hagan (2001), Oakley and O'Hagan (2002), Oakley and O'Hagan (2004), and Kennedy (2004). Bijak et al. (2013) also provide an in-depth account of the applications of emulation for demographic uses, including an example of sensitivity analysis using an emulator.

The input data D to which the emulator is fitted come from the experimental sample (Latin Hypercube sample) also used in the regression metamodel. D contains data from a set of N experimental points (in our case, the 224 unique points from the LHS). Let $f(.)$ denote the simulator. A Gaussian Process emulator can be defined as (Oakley and O'Hagan, 2002):

$$[f(.)|\theta, \sigma, R] \sim N[m(\cdot), \theta^2 c(\cdot, \cdot)] \tag{3.3}$$

where, m denotes the mean of the process that is modelled through a regression model of x, h(x), with coefficients θ such that for every output $f(x), m(\cdot) = h(\cdot)^T\theta. c(\cdot, \cdot)$ denotes the correlation matrix based on a roughness matrix $R = diag(r_1, ...r_n)$ which captures the responsiveness of the emulator to changes in particular inputs. A 'nugget' term to account for simulation stochasticity of the emulator can be incorporated in the estimation of the mean and covariance matrix. If assumptions about the prior distributions of the parameters of the emulator are included, a full Bayesian approach for uncertainty and sensitivity analysis can be applied to obtain a posterior distribution of f given D. While the full range of analysis that can be carried out with the emulator particularly with respect to using the model for prediction purposes and uncertainty analysis are wide-ranging, our immediate focus is on building emulators to perform a variance-based sensitivity analysis. For the purpose of our sensitivity analysis, we standardize the input parameters from our simulation model (α, γ, σ, β, ϕ, ρ) between 0 and 1 and assume them to be described by a uniform distribution: $unif(0, 1)$. Since the minimum and maximum values of already assume a range of theoretically plausible values, our assumption of uniform priors gives equal probability to values within this theoretically plausible range in the absence of other information that would be helpful to reduce uncertainty.

The output variance percentages for the three outputs derived from fitting an emulator separately to each are summarised in Table A.3.2. These variance

percentages denote how much of the variance in the output is attributable to different parameter combinations. It should be noted that the denominator for these variance-based sensitivity measured from the emulator take the proportion of the variance explained by the inputs, given input distributions, that is, $E[Var(f(x))]$ where $f(.)$ is the simulator. This should theoretically sum to 1 and is thus not directly comparable to an R-squared measure from the regression metamodel. In Table A.3.2 when the total <1, this implies there are other interaction terms accounting for the variation that were not explicitly estimated. In contrast, in the regression-based ANOVA analysis (see Table 3.1 in the main text) the denominator is the total variance in the data, with the unexplained variance captured in the residual variance term.

The model fit measure is especially sensitive to ϕ, the inflection point for technology diffusion, followed the readiness to abort parameters of σ and β. For the SRB 1990 output measure, the technology diffusion parameters matter, with ϕ again explaining a sizeable fraction of the variance followed by ρ, the rate of technology diffusion, and σ, the readiness to abort parameter at parity 1 and above. The maximum SRB is most sensitive to σ and β, the readiness to abort parameters. These conclusions concur with those reported from the analysis of variance (ANOVA) in the main text of the paper.

3.A.5 Metamodel Crossvalidation

For both the regression metamodels and the emulators, we test how well the metamodels compare with the simulator at a sample of 88 input combinations taken from outside the input LHS (training) sample. We compare metamodel predictions with the simulator's output at these points. We calculate the cross-validation root mean squared error (RMSE), which measures the average error between the simulator and the metamodel at a given combination of parameters, and normalised root mean squared error, which measures how much (expressed

as %) of the input range (from the LHS data D) the average error spans. A normalised RMSE of 0.07 would indicate that the average error spanned 7% of the range of values for that outcome in the input sample. These are reported in Table A.3.3. The RMSE values, particularly for the fit measure, indicate that the metamodels do quite well at predicting the model fit measure, the SRB at 1990, and maximum SRB at different input points, with the average error within 10% (normalised RMSE < 0.1 except in max SRB) of the input sample range. Other than for the measure of model fit, where the emulator performs better than the regression metamodel, the cross-validation performance for both metamodels are similar.

Table A.3.1: Standardised coefficients from best-fit regression metamodels predicting three outcomes from simulation experiments: 1) model fit measure; 2) SRB 1990; 3) maximum SRB.

Parameters	Model Fit Measure	SRB 1990	Maximum SRB
α	−0.61	2.14	−0.33
γ	1.37*	−1.10	0.90
σ	−7.17***	17.11***	11.78***
β	−3.28***	0.26	4.93
ϕ	0.69	0.94	1.49
ρ	1.7*	−17.19***	−5.02
γ^2	−2.71***	2.67	0.89
σ^2	3.54***	−10.90***	−5.74
β^2	0.71	2.73*	−3.31
ϕ^2	3.22***	−5.57***	−1.32
ρ^2	−2.04***	9.59***	2.16
ρ . ϕ	3.72***	14.28***	4.40
σ . ϕ	−2.68***	1.05	−2.55
β . ϕ	−0.76	−0.91	−1.66
σ . ρ	0.91	7.42***	2.28
β . ρ	−1.84***	4.14*	0.11
σ . β	5.62***	0.15	1.18
γ . σ	3.52***	2.51*	4.11***
γ . ρ	−0.92	5.62**	1.18
γ . ϕ	−0.83	0.87	−0.92
α . β	2.29***	−2.59*	0.89
β . ϕ	1.61***		
α . ρ	1.11**	0.45	1.88
α . ϕ	−1.67***	−1.66	−1.16
α . γ		0.09	0.43
σ . ϕ . ρ		−23.9***	−5.25
β . ϕ . ρ		−11.69**	−4.04
γ . ϕ . ρ		−17.40***	−3.71
Intercept	3.93***	106.99***	110.39***
Multiple R-squared	0.7739	0.8701	0.7916
Adjusted R-squared	0.7602	0.8605	0.7731

*p < 0.05, **p < 0.01, ***p < 0.001

Table A.3.2: Variance (%) explained by different parameters and their interaction for three outcomes measures: 1) model fit measure; 2) SRB in 1990; 3) maximum SRB as estimated from the Gaussian process emulator.

Parameter	Fit Measure (RMSE)	SRB 1990	Maximum SRB
α	0.13	0.27	1.18
γ	5.01	4.13	14.33
σ	5.32	13.81	47.68
β	3.46	6.72	23.12
ϕ	37.39	48.23	7.43
ρ	4.86	6.42	1.02
$\alpha.\gamma$	0.11	0.01	0.05
$\alpha.\sigma$	0.33	0.03	0.11
$\alpha.\beta$	0.05	0.02	0.03
$\alpha.\phi$	0.53	0.18	0.03
$\alpha.\rho$	0.06	0.04	0.02
$\gamma.\sigma$	4.90	0.54	1.56
$\gamma.\beta$	2.21	0.15	0.11
$\gamma.\phi$	2.88	1.10	0.42
$\gamma.\rho$	0.36	0.54	0.06
$\sigma.\beta$	11.05	0.11	0.23
$\sigma.\phi$	4.00	5.32	1.34
$\sigma.\rho$	0.45	0.31	0.22
$\beta.\phi$	1.30	2.72	0.56
$\beta.\rho$	0.20	0.28	0.17
$\rho.\phi$	5.78	5.75	0.11
Total	90.38	96.68	99.78

Table A.3.3: Summary of cross-validation statistics indicating metamodel fit with simulated data for two classes of metamodels: 1) regression metamodel; 2) emulator.

		Regression Metamodel	Emulator
Model Fit Measure	RMSE	0.64	0.25
	Normalised RMSE	0.10	0.04
SRB 1990	RMSE	1.51	2.52
	Normalised RMSE	0.07	0.09
Maximum SRB	RMSE	1.88	1.87
	Normalised RMSE	0.12	0.12

Chapter 4

Comparing the Indian and South Korean Sex Ratio Transitions

4.1 Overview

This chapter extends the RWA simulation model presented in Chapter 2 to Indian SRB trajectories and contrasts the SRB trajectories of both India and South Korea to describe how different micro-level patterns can be used to describe their distinctive trajectories.[1] South Korea witnessed the emergence of skewed SRBs alongside a rapid fertility decline in the 1980s. By the 1990s SRBs started to level off and very soon afterwards by the mid-1990s SRBs showed a remarkable turnaround towards normalisation (see Fig. 3.2 in Chapter 3). By the mid-2000s SRBs had already returned to near normal levels. The Indian case in contrast witnessed a later rise in SRBs in the 1990s, followed by a levelling off that began in the mid-to late-2000s (see Fig. 2.1 in Chapter 2). The future course of SRB trajectories in India remains open to question. Will the turnaround to normal or near-normal levels in India be as rapid as that witnessed in South Korea? By calibrating the simulation model to recreate the Indian SRB trajectory from

[1] A modified version of this chapter has been published as Kashyap, R. and F. Villavicencio (2017). "An Agent-Based Model of Sex Ratio at Birth Distortions." In A. Grow and J. van Bavel (Eds.), Agent-Based Modelling in Population Studies: Concepts, Methods, and Applications. Springer.

the bottom-up, we can also explore the future implications of changing fertility preferences and reproductive behaviours.

4.2 The South Korean Sex Ratio Transition

4.2.1 Results

This section briefly recapitulates the insights derived about the South Korean calibration that have been presented in detail in Chapter 3. Additionally, it presents a closer examination of the impact of the parity 0 abortion parameter β in shaping South Korean SRB trajectories.

Figure 4.1 shows SRB and fertility trajectories from the model calibrated with UN WPP mortality and fertility rates for South Korea, and son preference time series from Korean fertility surveys, across two sets of parameter values, one with $\beta = 0$ and the other set with $\beta = 0.2$. We calibrate the model by trying to match as much as possible the smoothed UN SRB and fertility estimates shown in Fig. 4.1, which are indicated by the lines in grey in the figure. The simulated $\beta = 0$ curve in Fig. 4.1 shows 5-year moving averages of SRBs averaged across 25 simulation runs, with the following parameter values: $\gamma = 0.20$, $\alpha = 0.075$, $\upsilon = 0.5$, $\phi = 7$, $\sigma = 1.7$ and $\beta = 0$. These parameters allow for a rapid diffusion of technology with saturation of technology by the early 1990s and a very intense fertility squeeze at parity 1 and higher but with no parity 0 abortion ($\beta = 0$). $\sigma = 1.7$ implies that given the levels of fertility decline between 2.4 to 1.6 between 1980–1990 when SRBs steadily rose, probabilities to abort for those with access to technology and unmet son preference who had a daughter as their first child rose from ∼71% to 100%.[2] At parity 2 and higher and $\sigma = 1.7$, all individuals with an unmet son preference and access to technology transitioning to third

[2]If TFR = 2.4, $\min\{1, (parity \times \sigma)/\text{TFR})\} = \min\{1, (1 \times 1.7/2.4)\} = 0.708$. If TFR = 1.6, $\min\{1, (parity \times \sigma/\text{TFR})\} = \min\{1, (1 \times 1.7)/1.6)\} = \min\{1, 1.0625\} = 1$.

birth would practice sex-selective abortion over the whole period. With abortion delayed to parity 1 and higher with $\beta = 0$, even as son preference was declining, the steady diffusion of technology in the 1980s combined with the increase in the probabilities to abort at parity 1 over the period lead to increasing SRB distortions in the model between 1980 and 1990.

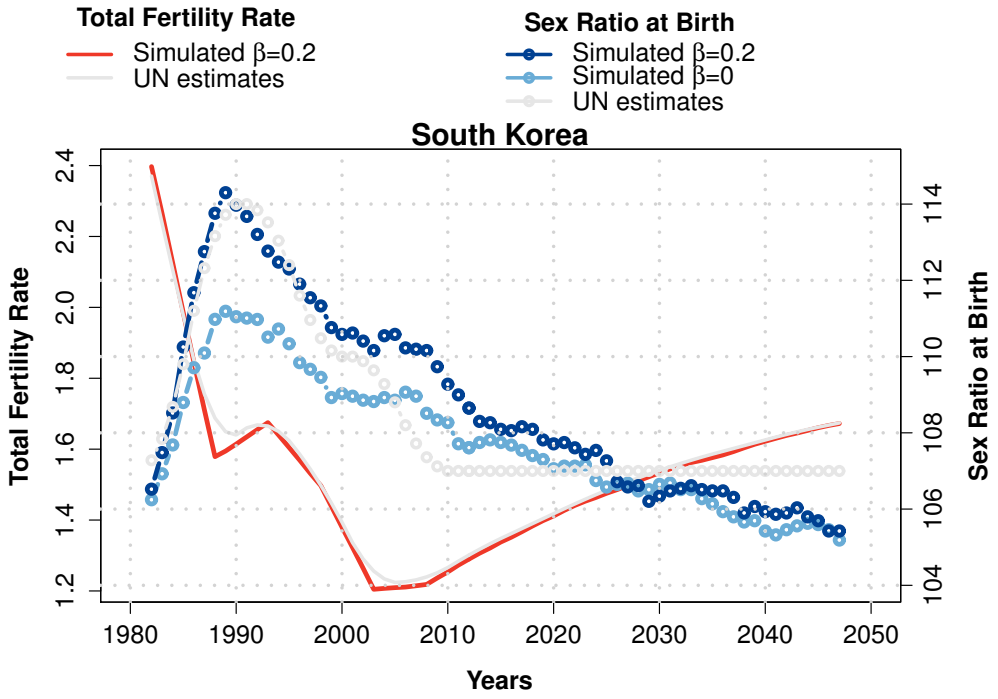


Figure 4.1: Simulated fertility (solid line) and sex ratio at birth (dotted-dashed line) trajectories, 5-year moving averages, South Korea 1980–2050

The most salient observation to be made from this simulated SRB curve with $\beta = 0$ is that while it matches a part of the rise in SRBs between the early to the mid-1980s due to technological diffusion and increasing readiness to abort at parity 1 due to declining fertility levels, it does not match the peak SRB levels observed in South Korea in the 1990s. We fall about 2–3 points short of the peak, reaching 111–112 instead of the observed 114. We cannot match these peak SRB levels of 114–115 by adjusting technological diffusion parameters or increasing σ. By adjusting these parameters we worsen the fit over the 1980s with a curve that rises too early.

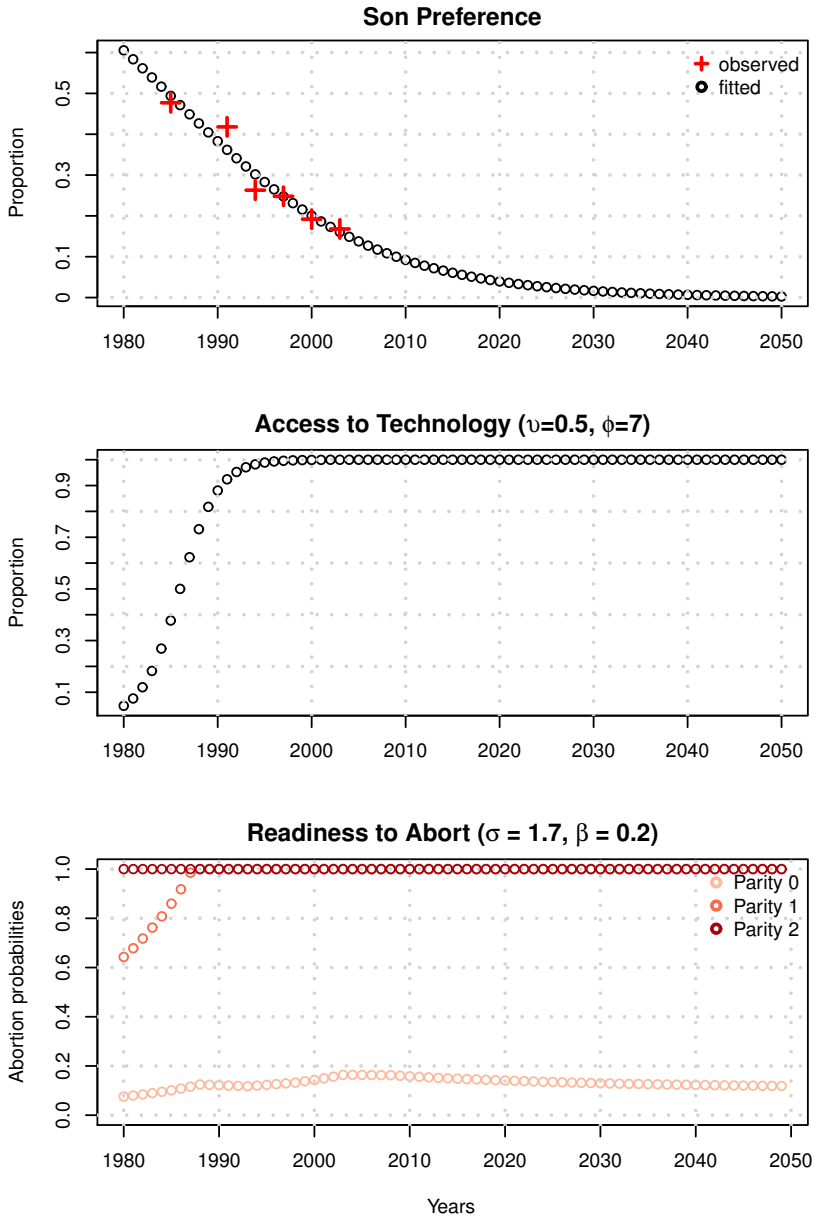


Figure 4.2: Son preference (*willingness*), access to technology (*ability*) and parity-specific abortion probabilities (*readiness*) over time, 1980–2050, for South Korea used in simulations.

Instead, gradual adjustments in β that allow for small and increasing probabilities of sex-selective abortion at parity 0 keeping all other parameters the same as before enable us to better match the peak and turnaround in SRBs observed in South Korea. The simulated SRB and TFR levels with $\beta = 0.2$ reported in Fig. 4.1 share all parameters in common with the $\beta = 0$ simulated curve except for their difference in allowing sex-selective abortion at parity 0 (these parame-

ters are: $\gamma = 0.20$, $\alpha = 0.075$, $\upsilon = 0.5$, $\phi = 7$, $\sigma = 1.7$). While our simulated trajectories do not perfectly match with the observed ones reported in UN data, they follow the general shape that was observed in South Korea between 1980 and 2000 relatively well. After the mid-2000s our simulated estimates fall slower towards normalisation than was observed in South Korea. The logistic fit for the son preference data for South Korea shown in the topmost panel of Fig. 4.2 indicate that our fitted values slightly under-predict the change in son preference in the early 1990s, which may be one possible reason for why our turnaround starts slower.

A son preference intensity parameter of $\gamma = 0.20$ and birth risk adjustment of $\alpha = 0.075$ allow us to match Korean fertility trajectories over the period, with the prevailing levels of son preference very well. This implies that for those with unmet son preference fertility risk was higher by about 20%. The UN projections of the SRB for South Korea hold it constant at 107—slightly higher than what is considered biologically normal levels of 104-106—starting 2010 until 2050. Allowing the underlying behaviours to change according to the trends reported in Fig. 4.2, our model suggests that SRBs will fall even lower towards more normal levels of 105–106 after the mid-2020s.

4.3 The Indian Sex Ratio Transition

4.3.1 Model Calibration for India

For both India and South Korea, the model uses age-specific mortality and fertility rates from the UN WPP (United Nations, 2013). Measures of son preference, however, come from different fertility surveys for each country. Details of how an individual's probability of having son preference is modelled generally is described in Chapter 2 under the sub-section on 'Son Preference (Willingness)' in the section on 'Modelling Reproductive Behaviours'.

For South Korea, we use a measure for son preference which asks women to report if they feel they "must have a son". This question has been asked in Korean fertility surveys carried out by the Korean Institute for Health and Social Affairs. To calibrate the model for India, we pool data from ideal fertility preferences questions asked across three waves of the National Family Health Survey (NFHS) (1992–93, 1998–99, 2005–06) to approximate a measure of son preference.[3] This question asks women between the ages of 15-49 to report on the ideal number of sons they desire. The data reveal that mean son preference, as measured by average of the ideal number of desired sons, fell at a rate of 3.7 percent across successive five-year cohorts from those born 1940–44 to 1970–74. This decline in mean son preference across cohorts was largely due to a decline in the proportion of women reporting a desire for more than one son (specifically declines in an ideal number of two or three sons). When we dichotomise this variable to see how proportions desiring at least one son vary by cohort the change is less salient at just under 0.2 percent decline across successively younger birth cohorts. We interpret this as an indication that while the decline of higher order son preference (an ideal preference for two or three sons) may be related to a wider decline in the preference for large families, fertility decline does not equally rapidly erode norms surrounding a desire for one son.[4]

Logistic regression analysis of the pooled NFHS data with the dichotomised son preference variable as the outcome revealed that both period (of the survey) and the cohort that the female respondent belonged to were statistically significant predictors ($p < 0.001$) of son preference. The impact of the societal transformation and macro-level structural modernisation factors such as urbanisation and educational expansion on demographic behaviour are captured well by using

[3]The National Family Health Survey (NFHS) is the name by which the Demographic and Health Survey (DHS) is called in India. Data for all three waves of the NFHS are available at `http://www.dhsprogram.com/Data/`.

[4]This concurs with conclusions reached by Bhat and Zavier (2003) in their analysis of ideal fertility questions from the NFHS.

the concept of cohort (Ryder, 1965) and cohort changes in fertility preferences and behaviours (e.g desired family size, contraceptive use) are well-documented across the developing world (Pasupuleti and Pathak, 2011; Cleland et al., 1994). While cohort effects are statistically significant in explaining son preference decline in India, we find that period effect size is larger. This is in line with previous research in South Korea that also found period effects to be larger than cohort effects in explaining the decline of son preference (**?**). We use the coefficients from the logistic regression to project both backward and forward for time-steps and for cohorts for which we do not have observed data on stated son preference. The predicted proportions of individuals with son preference in the population at time t and from cohort c can be expressed as:

$$sp_c(t) = \frac{e^{\beta_0+\beta_c+\rho\, t}}{1 + e^{\beta_0+\beta_c+\rho\, t}} \tag{4.1}$$

In Eq. (4.1), β_c refers to the coefficient of son preference change by cohorts, ρ refers to the coefficient of son preference change over time and β_0 to the intercept. The three parameters β_0, β_c and ρ are estimated from a logistic regression fitted to the NFHS data with the two covariates. Figure 4.3 plots mean son preference over time extrapolated backward to 1980 (the first year of the simulation) and forward until 2050 from the coefficients of the logistic regression. Since the proportion of son preferring individuals at any given time t is different for different cohorts, mean son preference here indicates the simple mean of son preference individuals aged 15–50 in that particular year (all fertile cohorts).

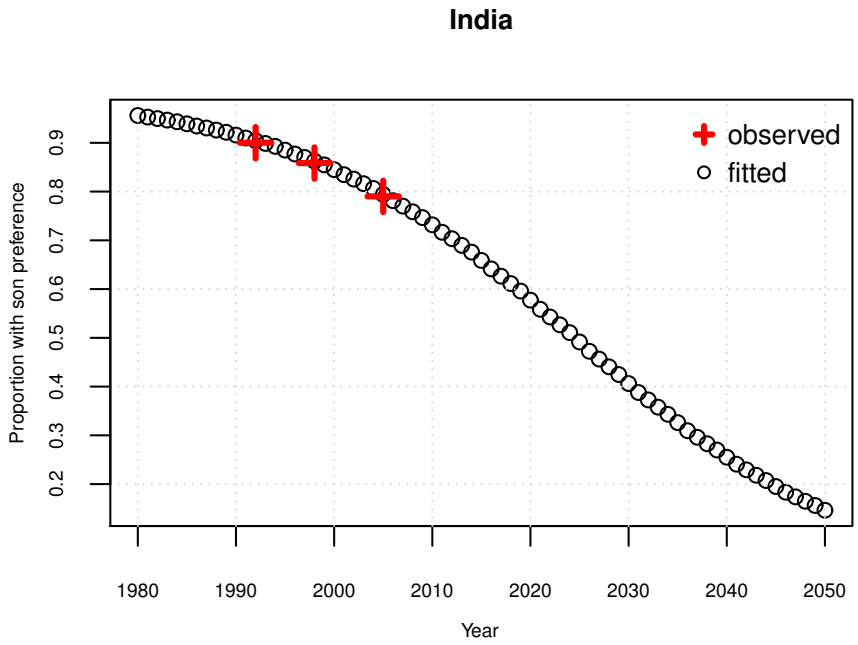


Figure 4.3: Proportion with son preference, India 1980–2050. Source: Observed values from fertility preference data from National Family Health Survey (1992-93; 1998-99; 2005-06)

For India, we were additionally able to access a data source to approximate the timeline of ultrasound diffusion for the population. To approximate a general shape for the technological diffusion curve over the time from 1980 onward for India we rely on data points on proportion of women reporting ultrasound use during their most recent pregnancy from the District Level Health Survey (DLHS)-I-III data reported in Akbulut-Yuksel and Rosenblum (2012). The authors of that paper report this proportion by regions for India and estimate this proportion for births for each year for a period spanning 1999 and 2008. We average across all regions to approximate national-level technological diffusion for india. We should note that we could not find similar data to generate a timeline of ultrasound diffusion and uptake for South Korea. As a result we estimated technological diffusion for South Korea by conducting sensitivity analyses for the

model across a range of technology diffusion (υ and ϕ) parameters. The best fit to these data points from the diffusion process used to model ability (see Eq. (2.3) in chapter 2) is of $\upsilon = 0.13$ and $\phi = 33$.

4.3.2 Results

In contrast to the South Korean sex ratio transition, SRBs measured at the national-level in India peaked later and stayed lower at levels of 111. Moreover, unlike the South Korean case, SRBs appear to have levelled off in recent years but have not shown the dramatic turnaround they did in South Korea. Son preference levels, using the measure we calibrate for the model from the NFHS, indicate that son preference was higher than levels in South Korea and declined slower in India.[5] What does the model suggest were the reasons that SRBs did not reach levels comparable to those in South Korea? The fact that SRBs reached 111 when fertility levels were over 2.5 children per woman in India compared with the South Korean case where SRBs peaked when TFR was well below 2 suggest that the fertility squeeze was likely lower in India than in South Korea. Individuals were much less likely to abort at lower parities, with evidence suggesting the greatest distortion was observed at parity 3 and higher (Arnold et al., 2002). Secondly, technological diffusion plausibly happened much earlier and more swiftly in South Korea than India due to South Korea's comparative wealth and development and less heterogeneity in the access to ultrasound. The literature widely acknowledges that technology was not widespread in the early 1980s and diffused more gradually over the course of the 1990s in India (Patel, 2007; Arnold et al., 2002).

Figure 4.4 reports the dynamic trajectories and associated parameters of *willingness* (son preference), *ability* (access to technology) and *readiness* (parity-specific abortion probabilities) that we use to calibrate SRB and fertility tra-

[5]Although here we treat them as roughly approximating proportions desiring one son at different time points in the model, we acknowledge these data come from different surveys and from questions regarding sex preference that were worded differently in each of the surveys and are not directly comparable.

jectories for India. The results from these simulations, 5-year moving averages across 25 simulations, are reported in Fig. 4.5.

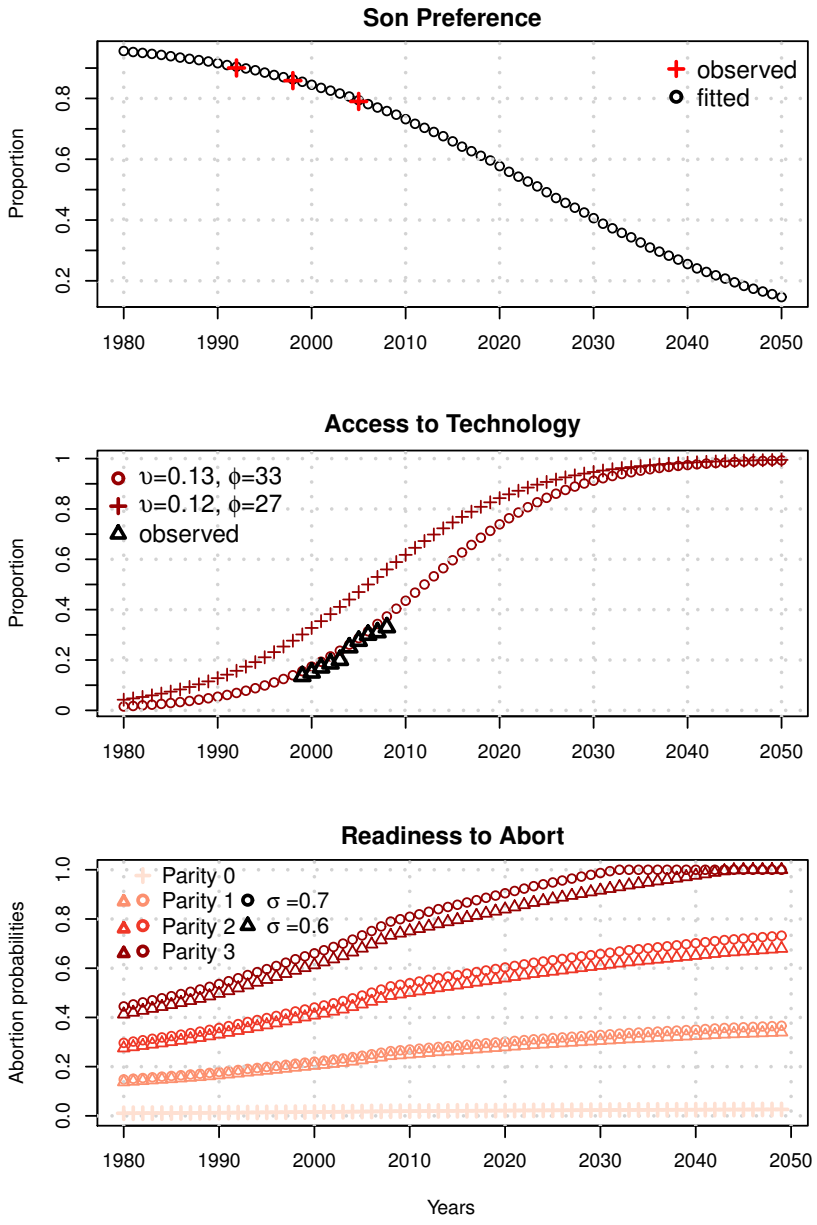


Figure 4.4: Son preference (*willingness*), access to technology (*ability*) and parity-specific abortion probabilities (*readiness*) over time, 1980–2050, for India used in simulations

We use two sets of parameters for India: in simulations with the first set of parameters we use the technological diffusion parameters of $\upsilon = 0.13$ and $\phi = 33$ estimated from the technological diffusion data points from the DLHS-I and II, and test the model with different values of the readiness parameters σ and β to

find the abortion probabilities that provide the best possible match to the UN estimates of the Indian SRB curve from 1980–2013, which are depicted by the grey curve in the Fig. 4.5. The best possible fit obtained with $\upsilon = 0.13$ and $\phi = 33$ is reported in the simulated curve with $\upsilon = 0.13$, $\phi = 33$ and $\sigma = 0.7$ in Fig. 4.5. To improve upon the fit provided by these parameters, we adjust technological diffusion by allowing for an earlier inflection point with $\phi = 27$, and a slightly slower rate of increase with $\upsilon = 0.12$, and a slightly lower fertility squeeze parameter of $\sigma = 0.65$. In both simulated SRB curves depicted in Fig. 4.5 we keep $\beta = 0.05$ to allow for negligible parity 0 abortion, and hold son preference intensity parameter $\gamma = 0.125$ and the birth risk adjustment parameter $\alpha = 0.075$.

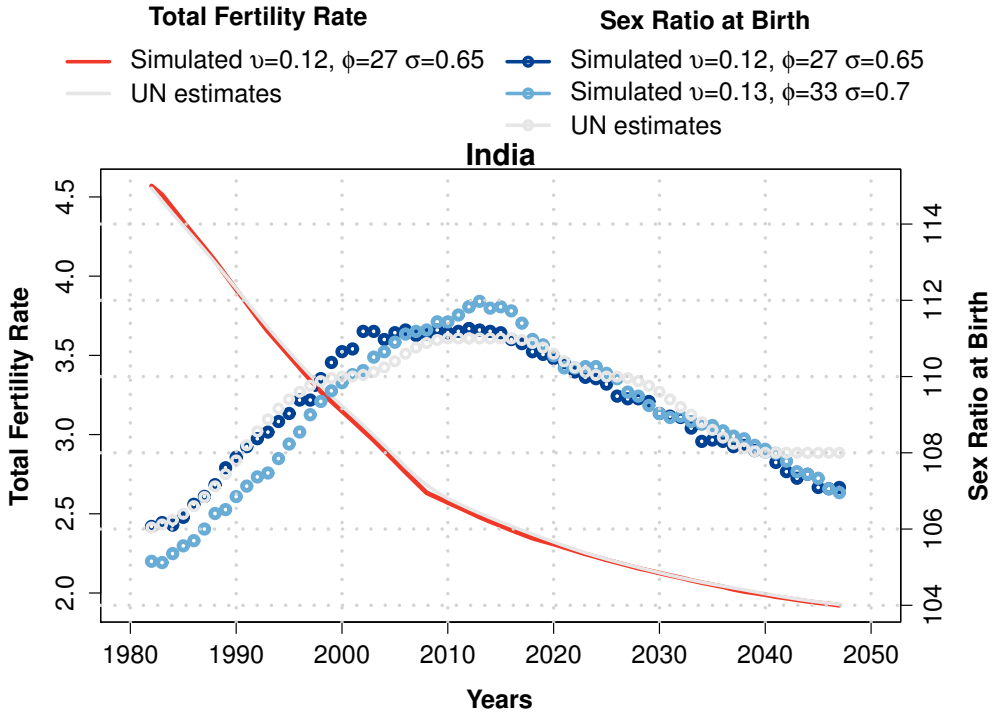


Figure 4.5: Simulated fertility (solid line) and sex ratio at birth (dotted-dashed line) trajectories, 5-year moving averages, India 1980–2050)

The simulated SRB curve with earlier technology diffusion $\upsilon = 0.12$, $\phi = 27$ and lower $\sigma = 0.65$ provides a better fit to Indian SRB trajectories between 1980 and 2013 than the curve generated by $\upsilon = 0.13$, $\phi = 33$ and $\sigma = 0.7$. The model fit demonstrates how the intensity of the fertility squeeze was much lower in India

than in South Korea, with values for σ as well as β significantly lower than those used for model fitting in South Korea. Our model suggests that few individuals likely aborted at low (parity 1 or parity 2) or very low parities (negligible at parity 0) in India (see probabilities to abort in Fig. 4.4). The rise in SRBs observed between the mid-1980s and 2010 was caused by the diffusion of technology starting in the 1990s and small increases in the probability to abort that accompanied the fertility decline, with the greatest probabilities to abort in the transition from second to third birth, and higher. The slower decline in son preference in India accompanied by a slower, flatter diffusion of technology generates a flatter SRB trajectory with a less sharp peak compared with South Korea. It is interesting to note that the SRB peak in South Korea roughly coincided with the saturation of technology. Peak SRBs are generated by the model in the mid-2000s when technological access is $\sim$40% for the simulated $\upsilon = 0.12$, $\phi = 27$ and $\sigma = 0.65$ curve, and in 2010 for the simulated $\upsilon = 0.13$, $\phi = 33$ and $\sigma = 0.7$ SRB curve, when technological access is also $\sim$40%. Thereafter, even as technological access and abortion probabilities increase, SRBs begin to level off due to declining son preference.

The fertility trajectories generated by the best fit parameters ($\upsilon = 0.12$, $\phi = 27$ and $\sigma = 0.65$) are plotted in Fig. 4.5. These match UN TFR trajectories depicted by the grey line particularly well indicating that a good balance between son preference intensity that amplifies fertility and the fertility squeeze generated abortion probabilities that exert a downward influence on them. For the model calibrated for India, if an individual is son preferring their fertility rates are higher by 12.5% ($\gamma = 0.125$) and upon meeting their son preference, their rates fall by 7.5% ($\alpha = 0.075$). Projecting the best fit simulated SRB curve ($\upsilon = 0.12$, $\phi = 27$, $\sigma = 0.65$) for the period after 2010 indicates that SRB trajectories are likely in the midst of a turnaround presently in India, and will gradually fall towards levels of 107 by 2050.

4.4 Limitations, Discussion and Future Work

This chapter has described the application of the RWA simulation model to two contexts where macro-level SRB trajectories have had different shapes and reached different levels. South Korean SRB patterns, the model suggests, were underpinned by weak willingness, widespread ability and a high level of readiness to abort. In contrast, Indian SRB trajectories are flatter and less peaked on account of slower diffusion of technology indicating more heterogeneous ability and less intense readiness despite higher levels of willingness in the population. The microsimulation model provides a sufficiently general but useful approach to shed insights on the dynamics of macro-level SRB trajectories and approximate the micro-level processes underlying them.

Nevertheless, a number of limitations with the model can be identified. When designing and implementing a model such as this one, one significant recurring issue is the trade-off between model parsimony and complexity. By trying to adopt a parsimonious modelling approach, we may have simplified some processes in a manner that is either not easily approximated with existing data or perhaps a bit unrealistic. For example, we chose to model son preference dichotomously and its effect on fertility in time-constant γ (son preference intensity) and α (birth risk adjustment after meeting son preference) parameters. From a modelling and a theoretical perspective there is a strong case to be made, as we have tried to do, about incorporating son preference dichotomously and allowing its effects on fertility to be constant across time. As the effect of son preference on fertility at any time point is decided dynamically as a balance between the proportion son-preferring at that time and their upward effect on total fertility levels, as well as those meeting their son preference who exert a downward effect, we sought to measure and calibrate model-generated TFR trajectories with observed TFR levels as a validity check in the model. These model-generated TFR values also informed the abortion probabilities that affected the SRB levels, which further

endogenised model processes. Our reasoning was that if the survey data approximations of son preference were reasonable, then plausible, but not very small, values of time-constant γ and α parameters would allow us to generate simulated fertility trajectories that matched observed TFR and SRB trajectories from UN data.

Additionally, when modelling the probability for an individual at a certain time to have a son preference, we relied on survey data measures. The South Korean stated son preference measure, which captures the "necessity to have a son", we believe works well to capture the changing norm over time. This measure, however, is not readily available for other contexts. For the Indian calibration we relied on the ideal fertility questions from the DHS to approximate son preference. The Indian measure was a more general question on the ideal number of sons a respondent desires, which may be prone to rationalisation and may not capture the intensity of son preference very well in terms of the necessity to bear a son. In future extensions of this model, it would be useful to think about other measures of son preference or ways of approximating son preference through a revealed preference approach that examines the effect of the existing sex composition of children on fertility behaviour.[6]

A further issue in model design linked to the parsimony-complexity trade-off is one of how much is a necessary and useful amount of heterogeneity to incorporate in the model. For instance, we do not explicitly account for regional heterogeneity in the model in its current form. Our primary reason for doing this was because we were keen to use standardised UN data on fertility and mortality rates, which are available at the national level, as well as validate against SRB trajectories over time that are readily available at the national level. As is discussed in the next part of this thesis, temporal trends in the SRB at the subnational level in contexts such as India are harder to track. On the one hand, by generating SRB

[6]I thank Christophe Guilmoto for raising this point.

trajectories as the outcome of three micro-level processes that have differing rates of change, we account for heterogeneity in the model. We do not explicitly specify however what the source of this heterogeneity is. Regional heterogeneity may be seen as one implicit component of this overall heterogeneity. Nevertheless, an aggregate picture at the national level may be composed of extremely disparate trends at the regional level, whose impact cannot be assessed in the current version of our model. In India, for example, the regional nature of son preference has been widely noted in the literature, with son preference being concentrated in the north and northwest of the country (Das Gupta et al., 2003). Although national-level SRBs never reached levels comparable to those in South Korea and China, those in northwest India did (Guilmoto, 2009). Thus, one possible reason why national-level technological diffusion parameters fitted to survey data do not fit the SRB curve observed quite as well may be due to regional differences in technological diffusion that are not explicitly accounted for the model.

Beyond the individual-level mortality feedback effects on son preference for an individual, we also do not model other social feedback mechanisms and social network effects that may have important implications for understanding how son preference changes over time in a population. Indeed, this may be a reason why the model does not fully capture the dramatic turnaround in the 1990s in the South Korean SRB trajectory. The approximations of the three underlying processes for South Korea that our model generates are close to—but not enough—in explaining the significant change in the SRB that was observed in the country. More work on the exact mechanisms of change in son preference is certainly needed. We have chosen to refrain from incorporating such mechanisms at present because we believe the research on mechanisms driving the shift in son preference norms is still nascent. Moreover, and related to the previous point about heterogeneity, different mechanisms driving a weakening of son preference norms may exist in different regional contexts. A national-level model such as

this one might not in this case might not provide a suitable modelling approach. Qualitative studies focused on understanding mechanisms underpinning changes in norms could provide valuable insights that can be incorporated in simulation approaches to examine their macro-level implications. In extensions and applications of the model, we hope to incorporate these as well address the other issues we have raised.

As noted earlier, an important application of microsimulation models has been for projections (Zagheni, 2015). Although results presented from the model for India and South Korea have commented on the future course of SRB trajectories for each of the countries based on model outcomes, this has largely been a side observation rather than the core aim of the model. The model, however, could offer a valuable tool for projecting SRBs, and a substantively different approach than time series ones such as lagged models for projecting SRB trends that are used by the UN at present.[7] For projection purposes, more comparable estimates of son preference and adjustments of the willingness procedure would be preferable. Additionally, approaches to incorporate model uncertainty would be needed when extending the model for projection purposes. Statistical emulation, as discussed in the appendix to Chapter 3, could be a useful approach for this (Bijak et al., 2013).

Despite these limitations, the simulation model presented here provides a contribution to the literature that is powerful in the insights it provides and flexible enough to be adapted to different contexts. While each geographical context has its own set of underlying factors that will determine the course of future SRB trajectories, the model presented here provides a valuable computational tool that will enable researchers to test the implications of unique sets of micro-level forces—individual fertility preferences, behaviours, and technology use—to explain both current macro-level trends and to potentially project future ones.

[7] I am grateful to Leontine Alkema for a helpful discussion about the issue of SRB projections.

Part II

Indirect Estimation of the Sex Ratio at Birth with Web Data

Chapter 5

Ultrasound Technology and 'Missing Women' in India: Analyses and Now-casts Based on Google Searches

5.1 Introduction

Chapters in Part I of this thesis have focused on national-level SRB patterns. However, patterns of son preference and sex selection, as well as ultrasound availability, can vary significantly across regions within a country. This is especially so in diverse and heterogeneous contexts such as India, where regional differences in son preference and population sex ratio imbalances have long been been noted in the literature (Miller, 1987; Dyson and Moore, 1983; Visaria, 1969). Subnational patterns in Indian SRBs are more challenging to track due to variations in data quality about birth registration across states, with available data often being erratic and not up-to-date (Attané and Guilmoto, 2007; Ganatra, 2008).

Simulation studies presented in Part I of this thesis highlight how SRB trajectories are highly sensitive to the timing and speed of the diffusion of prenatal sex determination technology in contexts with entrenched son preference. Starting from this insight, this chapter uses a novel source of data – information from Google search volumes related to ultrasound and sonography – both at the na-

tional level and at the level of Indian states to assess whether these data track the regional and temporal dynamics of SRBs.[1] The analysis presented in this chapter reveals that for the 2011–2014 period, states with distorted SRBs tended to display high search activity for ultrasound. Drawing on between-state variation in ultrasound search intensity for the period between 2011 and 2013, we 'now-cast' the 2014 SRB using Google search data. For wealthier states, we find that Google search performs better than lagged variable models in predicting the SRB, highlighting its potential role for indirect demographic estimation. By analysing a population's search footprints, these Google search data exemplify how big data can be used to study behaviours that are not readily measured, and to supplement existing but often slower or incomplete data sources (e.g., census or civil registration) in the developing world with more 'real-time' information.

5.2 Background

5.2.1 Missing Women

In a number of countries, largely in Asia, parental preferences for sons are so strong that they leave their imprints on populations in the form of distorted, unnaturally masculine sex ratios. In 1990, when Amartya Sen famously characterised these population-level distortions in terms of 'missing women', this phenomenon was largely the consequence of postnatal sex selection. Postnatal sex selection took the form of female infanticide or sex-selective allocation of resources, which resulted in higher than biologically normal levels of mortality for girls (Sen, 1990). The widespread diffusion of ultrasound technology that has facilitated the early, safe, and inexpensive detection of the sex of the foetus has enabled parents with strong son preferences to avoid unwanted female births by

[1]This chapter presents materials from the following co-authored study – Kashyap, R., F. Billari, N. Cavalli, E. Qian and I. Weber, "Ultrasound technology and 'missing women' in India: Analyses and now-casts based on Google searches."

practicing sex-selective abortion (Bongaarts, 2013). The practice of prenatal sex selection has led to the increasing masculinisation of the sex ratio at birth (SRB) across a number of countries in South, East and West Asia (Guilmoto, 2009). SRBs in human populations, measured as the number of live male births for every 100 female births in a given year, are largely stable around 104-106. In parts of countries such as India, China, South Korea, Vietnam, Azerbaijan, Armenia, and Georgia, the SRB since the 1990s has well exceeded 105, sometimes reaching levels of 120 male births for 100 female births or more. These distortions persist even as prenatal sex screening of the foetus in several SRB distorted countries, such as China and India, is outlawed (Ganatra, 2008). According to most recent estimates by Bongaarts and Guilmoto (2015), between 1980 and 2015 around 33 million girls were missing from the global population due to prenatal sex selection.

Since the 1980s and 1990s, ultrasound, which can determine the sex of the foetus as early as 11 weeks, is the most widely used technology for sex determination of the foetus (Chen et al., 2013; Ganatra, 2008; Mahal et al., 2006). Data about the access and uptake of ultrasound, especially in contexts where there is likely to be regional heterogeneity due to varying access to medical facilities or different levels of development, are often limited. Although measures for ideal fertility preferences, such as ideal number of sons desired such as those reported in the Demographic and Health Surveys, are available, these measures are often prone to rationalisation or may not adequately capture the intensity of son preference in driving reproductive behaviours. Moreover, social campaigns such as the 'Beti Bachao, Beti Padhao' (save daughter, educate daughter) launched by the Government of India, that attempt to enhance the value of daughters and discourage son preference might make the public expression of son preference socially undesirable (Patel, 2007). Even though data on ultrasound diffusion are often sparse, the importance of growing access to this technology in generating SRB distortions has been noted by a number of demographic studies, including

simulation studies presented in Part I of this thesis (Kashyap and Villavicencio, 2016; Chen et al., 2013; Guilmoto, 2009; Bhat and Zavier, 2003).

5.2.2 The Indian Context

Son preference and its demographic manifestations have been widely noted in India (Bongaarts, 2013; Arnold et al., 2002; Retherford and Roy, 2003; Arnold et al., 1998; Das Gupta and Bhat, 1997). Until the mid-2000s, excess female deaths resulting from postnatal sex selection contributed more to missing women in India than missing female births. By 2010-15, however, missing female births contributed more to missing women in India than excess female deaths (Bongaarts and Guilmoto, 2015). Our calculations, drawing on Bongaarts and Guilmoto (2015) indicate that between 1980 and 2010 there were approximately 10 million missing female births arising from the practice of prenatal sex selection in India alone, accounting for about a third of the total 33 million missing female births worldwide. Although a ban on prenatal sex determination has existed in India since 1994, demographers generally believe it has not been effective and have emphasised the need for alternative strategies that seek to weaken son preference norms (Guilmoto, 2015; Patel, 2007). Access to abortion is relatively liberal in India, with abortion permitted up to 20 weeks for a broad range of reasons (Ganatra, 2008).

One of the key features of SRB distortions in India is their regional variations (Guilmoto, 2009; Bhat and Zavier, 2007; Arnold et al., 2002). While national-level SRB levels have hovered around 110-111 male per 100 female births since the mid-2000s, SRB distortions in the northern and northwestern states of the country (see Figure 5.1 and the map of the child sex ratio (0–6 year olds) in Fig. 5.2), such as the states of Punjab, Haryana, Delhi, Rajasthan, Gujarat and Chandigarh, are significantly higher, often reaching 120 male births for 100 female births and above.

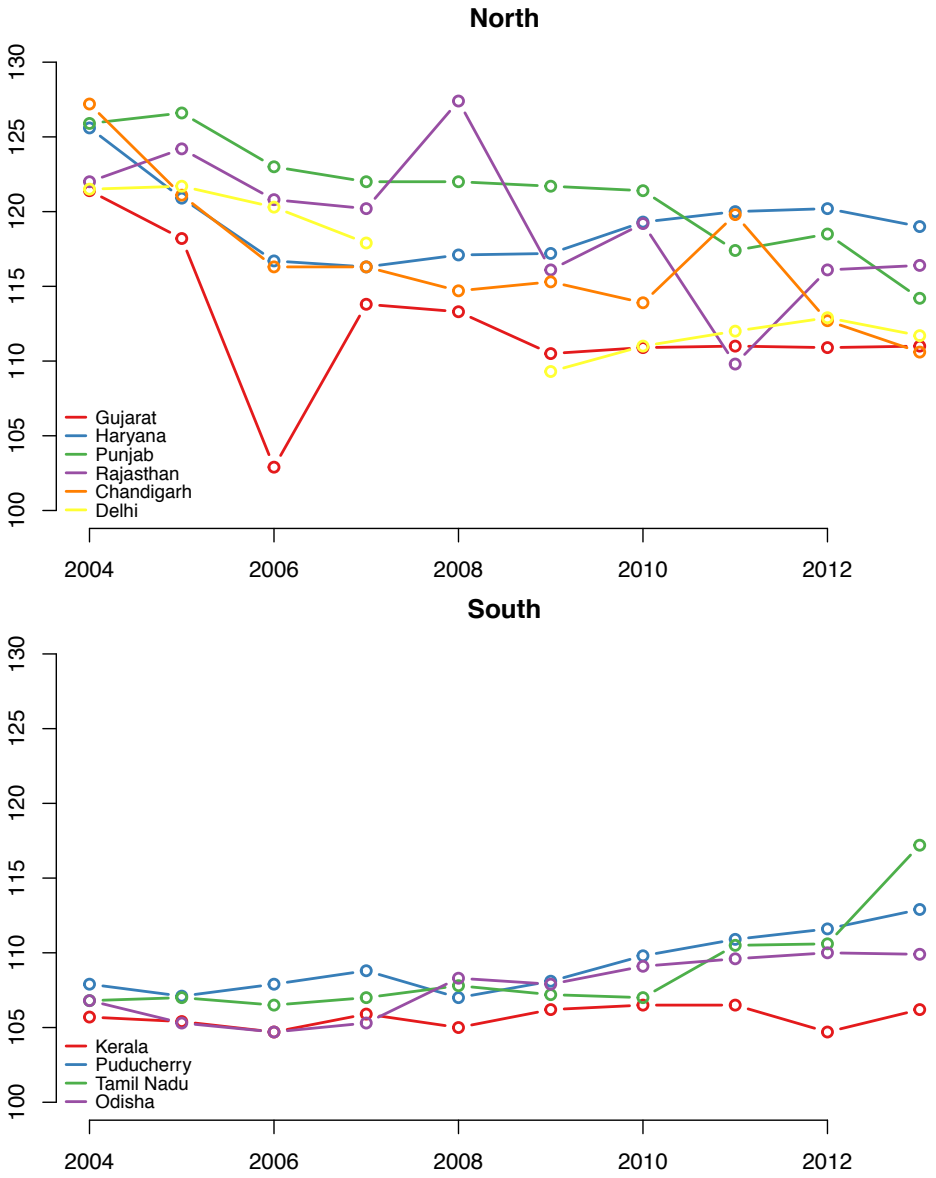


Figure 5.1: Sex ratio at birth (SRB) trends between 2004 - 2013 for select states in north and south India based on civil registration data.

Southern and northeastern Indian states have less distorted SRBs. These regional differences in SRB distortions are thought to reflect broader patterns of gender relations, kinship forms, and marital customs that give rise to son preference (Das Gupta et al., 2003; Dyson and Moore, 1983). North and northwest Indian states have historically had patrilineal kinship, where property, names and titles are transferred along the male line, and patrilocal marital norms, wherein the bride marries into her husband's family upon marriage and moves outside her

natal village. Whether or not such kinship systems give rise to dowry, by virtue of their 'organisational logic' they generate strong incentives to bear at least one son (Das Gupta et al., 2003).

In contrast to the north, south and southeast India have traditionally featured more matrilineal communities, with marriage norms that emphasise marriage to close kin and the maintenance of natal family networks for the bride. As a result of these differences in kinship and marriage forms, Dyson and Moore (1983) hypothesised that women had greater autonomy in the south and southeast as compared with the north and northwest of the country, thereby resulting in more gender equitable outcomes such as less son preference in the south. More recent literature, however, has challenged the continued relevance of Dyson and Moore's hypothesis for contemporary demographic patterns in India (Rahman and Rao, 2004). Sex-selective abortion and associated SRB distortions appears to be spreading in recent years to states such as Tamil Nadu and Odisha in southern India as the upward trend in the SRB for these states in Figure 5.1 indicates (Diamond-Smith et al., 2008; Basu, 1999). This spread may be the result of changing son preference patterns in these regions, or the spread and uptake of ultrasound in regions where it was previously unavailable.

5.2.3 Data on Sex Ratio at Birth in India

As an indicator for prenatal sex selection, the SRB has become a widely used to monitor gender discrimination (WHO, 2011; Guilmoto, 2012a). Despite this interest, SRB data in India face a number of challenges. Data at the state-level in India are often slow to be released, not readily available and/or suffer from a number of data quality problems. One of the key data quality concerns stems from the unreliability, in some states, of birth registration systems, which is the single most important source for SRB data (Ganatra, 2008; Attané and Guilmoto, 2007).

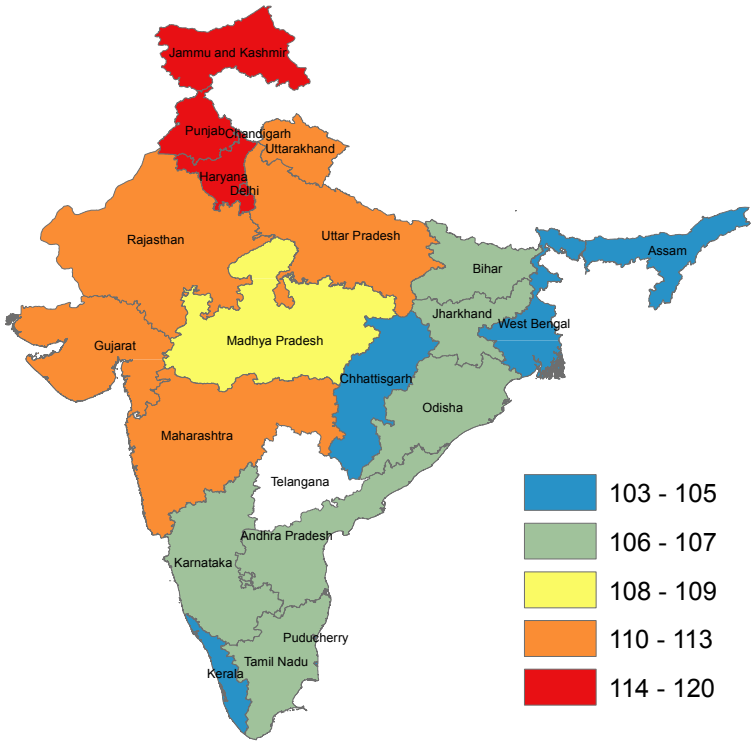


Figure 5.2: Child sex ratio from most recent census data (2011).

SRB statistics are likely to be more reliable in places where birth coverage is better. State-level statistical offices check the extent of coverage of their birth registration systems by assessing the estimates provided by the full registration of births against a random sample provided by the sample registration system (ORGI, 2016). Birth registration systems are generally better in richer, more developed states (e.g. Delhi, Punjab) and significantly worse in poorer ones (e.g. Bihar, Chattisgarh, Jharkhand). For the most recently published data on 2014 on the extent of birth coverage published by the Registrar General of India, birth coverage ranged from about 60% in Bihar to 100% in Delhi (ORGI, 2016). For the 2010-2014 period, 12 states had birth registration coverage of over 90% – Gujarat, Haryana, Punjab, Delhi, Rajasthan and Chandigarh in the north and

northwest, Maharastra and Goa in central India, West Bengal in the northeast, and Odisha, Kerala and Karnataka in the south.

Another issue affecting the reliability of SRB data may be the selective underenumeration of births, which is likely to affect female births disproportionately in a context of strong son preference. Although differential underenumeration has been noted as an important issue for the Chinese SRB due to the restrictions imposed by the one child policy (Goodkind, 2011; Merli and Raftery, 2000), differential underenumeration is at most a marginal factor in explaining sex ratio distortions in India (Griffiths et al., 2000) and there is little evidence that differential underenumeration has increased over time (Arnold et al., 2002).

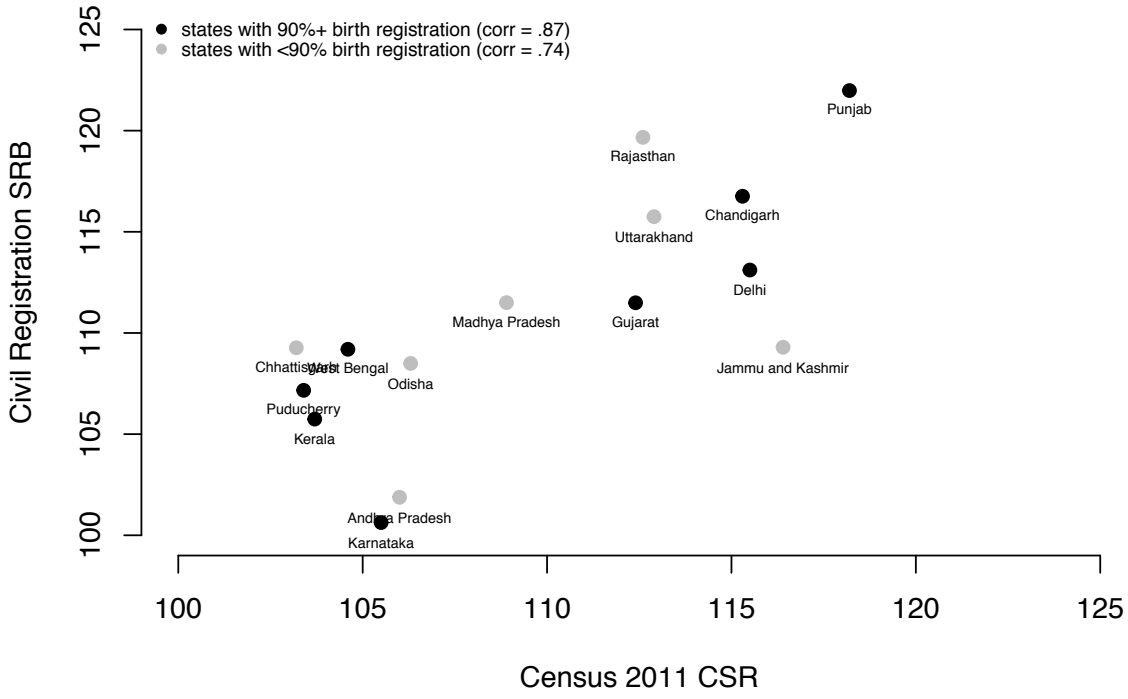


Figure 5.3: Census 2011 CSR and the civil registration SRB averaged across the six birth cohorts (2007-2011) that contribute to the 2011 child sex ratio.

In light of the shortcomings of SRB data derived from the civil registration for low birth registration states, demographic studies often report the Child Sex

Ratio (CSR), i.e., the male-to-female ratio of 0–6 year olds in the population, which is published in the Census of India (Diamond-Smith and Bishai, 2015). SRBs have also been indirectly estimated from Census CSR data using reverse survival methods (Kumar and Sathyanarayana, 2012). While the SRB captures only prenatal sex selection, the CSR captures both prenatal and postnatal forms of sex selection. However, the CSR is correlated with the SRB, as shown in Figure 5.3, which plots the Census 2011 CSR against the civil registration SRB averaged across the six birth cohorts (2007-2011) that contribute to the 2011 CSR. Fig. 5.2 highlights the regional variations in the child sex ratio (CSR) from the 2011 Census, which show how the most distorted sex ratios are concentrated in north and northwestern states of India. The correlation between CSR and SRB is stronger in high birth registration states. Although the Census provides wider geographical estimates and better population coverage than civil registration, particularly so for less developed states, it takes place once every ten years and data are slow to be released.

In terms of temporal trends from available civil registration data, Indian SRBs rose steadily from normal levels of 106 to distorted levels of 110-111 between 1990 and the early 2000s. After a phase of levelling off between the mid- to late-2000s, there is evidence for an incipient decline starting in the late-2000s (Das Gupta et al., 2009). National trajectories mask variations in regional-level trends in the SRB. Northern and central states showed either a gradual decline or relative stability in their SRB trajectories between the mid-2000s and 2014, which is the last year for which SRB data are available at the state level. SRB levels were higher in the north and central states than in southern states. See Figure 5.1 for state-level trends in the SRB for select high birth registration states in the north and south of India from their civil registration systems.

The Indian context, thus, presents an interesting case where ultrasound has increasingly become available across the country, and son preference exists but

varies between states. Whether this subnational pattern – with more distorted sex ratios in the north than in the south – will persist even as ultrasound becomes more readily available everywhere is an open question. Real-time tracking of the SRB, however, faces challenges due to limited data on the micro-level factors such as ultrasound access and son preference that underpin macro-level SRB distortions, as well as data quality challenges and slow timelines of official statistical agencies.

5.3 Google Search and Social Behaviour

As pointed out in the background, research on SRB faces several data challenges. Firstly, civil registration data are compiled slowly and may present issues in terms of the underlying quality of the data collection process. Secondly, information on the proximate determinants underlying SRB distortions – individual behaviours (i.e. access to ultrasound and the practice of sex-selective abortion) and attitudes (i.e. gender and abortion preferences) – are elusive and patterns of change in these behaviours at the macro-level over time are difficult to assess. In this context, information from internet searches can be very important, not least as it is collected extremely quickly and is generated by unprecedentedly large numbers of users. Reis and Brownstein (2010) noted that the use of search query data may be promising in the study of the interaction between abortion behaviours and policies in the United States, showing that data from online searches can be useful in complementing traditional data sources, as it can help in unveiling strategic behaviours of individuals faced with asymmetric policy constraints in a timely, efficient and transparent manner. Early indications on the usefulness of aggregate query logs to complement traditional data collection methods are put forward by Grimes et al. (2007). The idea is that it is possible to track

relatively simple, theoretically-relevant queries online to shed some light on non-trivial individual needs and attitudes in a reliable fashion (Liu et al., 2008).

Since its launch in May 2006, Google Trends has been deemed as a particularly promising tool to operationalise several of these research needs. Developed by Google Inc., Google Trends generates search volume data for a given keyword, available from 2004 up to the present. According to the public information made available by Google Inc., these data are generated from an unbiased sample, which represents only a percentage of all Google search data. If there is enough search volume, Google Trends provides information broken down at the local level, adjusting the data so that "each data point is divided by the total searches of the geography and time range it represents, to compare relative popularity". Google Trends provides data that are "scaled on a range of 0 to 100 based on a topic's proportion to all searches on all topics". This way, Google Trends provide synthetic indicators, comparable across time and space, for the interest of Google Search users toward any given set of keywords.[2]

Mostashari (2007) puts forward the idea of using Google Trends to gather data for public health surveillance, claiming that "a search for the term 'leptospirosis' in the United States finds dramatically higher rates of searches from Honolulu, Hawaii, consistent with the epidemiology of the illness in the United States". Following these seminal attempts, the interest of the research community toward Google Trends have been growing dramatically over time: a simple query for 'Google Trends' on the Google Scholar academic search engine returns 10,655 in the period spanning from 2004 to 2017, from 10 hits in 2004 to 2150 in 2016 (63 in 2017).[3]

Nuti et al. (2014) reviewed 70 Google Trends health-related papers published from 2009 to 2013, finding that 27% of the studies used Google Trends for causal

[2]Information on how Google Trends processes search queries to generate publicly available data is based on `https://support.google.com/trends/?hl=en#topic=6248052`.

[3]Data retrieved from Google Scholar on January 11, 2017.

inference, 39% for description, and 34% for surveillance, with an increase in publications over time and a median citation rate of 7 per article (close to the average of 7.64 recorded for scientific articles), suggesting "increasing awareness of and the leveraging of information from the [Google Trends] tool". The authors claimed that the large proportion of infectious disease articles (27%) "may stem from the precedent set by Google Flu Trends". Ginsberg et al. (2009) used a wide array of flu-related Google search queries to successfully track weekly influenza activity in U.S. regions from 2003 to 2008, as reported by the Centre for Disease Control and Prevention (CDC). Elected as a 'gold-standard' for bio-surveillance, the Google Flu Trends approach has been quickly rolled out in at least 29 countries worldwide and extended to other diseases, such as dengue and, more recently, to Zika (Teng et al., 2017). In 2013, however, Butler (2013) noticed that Google Flu Trends' "estimate for the Christmas national peak of flu is almost double the CDC's, and some of its state data show even larger discrepancies." Lazer et al. (2014) analysed some of the deeper causes for these discrepancies.

Google Trends has also been increasingly adopted for now-casting: Choi and Varian (2012) have argued: "We are not claiming that Google Trends data can help in predicting the future. Rather we are claiming that Google Trends may help in predicting the present. For example, the volume of queries on automobile sales during the second week in June may be helpful in predicting the June auto sales report which is released several weeks later in July". In their study, Choi and Varian (2012), integrated web search data with classical econometrics tools, such as autoregressive models, to find that the information captured by Google Trends can improve the quality of the out-of-sample forecasting of key economic variables.

Potential causes for concern relate to the representativeness of Google Trends data. In fact, internet users are a self-selected subsample of the general population, and Google users are themselves a self-selected subsample of the internet

users space. It is possible that Google Trends data entail a) an instability issue, due to the fact that regions with few users tend to have higher standard deviations in repeated searches from different timespan (according to our estimates, the countries in the lowest quartile in terms of internet users show a 20% higher standard deviation relative to the highest quartile); b) an early adopter issue, as people that use the web in countries where it is not widely developed may be characterised by unobserved variables (education, income, etc.) that are likely to be positively correlated to future-orientation.

Socio-economic segmentation is also relevant in countries where internet penetration rates tend to be higher. In fact, people with better access to the internet, or with better means to use it, may generate relatively more traffic, skewing the Google Trend sample toward richer, better educated users. In general terms, this is just a particular case of the problem of making inference from non-representative web samples as discussed, among others, in Zagheni and Weber (2015). To ease this concern, however, Zhu et al. (2012) compared the responses to offline telephone surveys and the prevalence of given search term from China using Google Trends and its analogous Baidu Index. Their study did not find any difference between users and nonusers in terms of their concerns over on the three issues under examination. This suggests that the concern that search queries only represent the interests of Internet users is unfounded.

In the case of India, Google's share in the search engines market touches 96%, but some concerns may apply. In the country, the internet penetration rate touched the 34.8% in 2016, with an estimated 30.5% year-on-year increase from 2015. In order to make results comparable across time, we normalise our search inputs by using relevant keywords. We use only English keywords, as almost the entirety of Indian internet users use English. However, India is a diverse country. Based on data from the 2011 census, it is possible to observe large variations in the internet penetration by state, from 0.9% in Bihar to 18.8% in

the administratively independent city of Chandigarh (the total penetration rate for India in 2011 was 10.1%).

5.3.1 Approach

5.3.2 Analytical Strategy

We use Google search data to track subnational patterns of the interest in ultrasound technology as a measure to capture increasing interest in prenatal sex determination and the readiness to consider prenatal sex selection. Given relatively limited information about use and uptake of ultrasound, these data are potentially useful to understand between-state interest in the technology, as well as useful to track temporal changes in interest in the technology. We first assess whether search interest in ultrasound is higher in states where sex ratios are more distorted by performing correlation analysis. We fit between and within-state regression models to test whether search interest in ultrasound tracks subnational and temporal changes in the SRB. Second, by training a model using civil registration SRB data from 2011 – 2013 from high birth registration states, we attempt to predict the SRB in 2014 using Google search indicators for ultrasound.

5.3.3 Data

We extracted data on Google search volumes using Google Trends for the terms 'ultrasound' and 'sonography' at the level of states in India. These search volumes are available weekly from 2008 onward. Prior to 2009, however, search volume is very low at the level of Indian states. From January 2011, Google implemented significant improvements in the geo-location of search queries. This implies that search data at the state-level are more reliable starting 2011. Rising interest in searches for ultrasound over time may of course reflect wider availability of internet and use of Google search in India. To account for this, we normalise

searches for ultrasound by looking at interest for other related medical technologies such as X-ray or magnetic resonance imaging (MRI), a diagnostic technology that has also become increasingly available in India since the 1990s. We create a number of different indices to capture the intensity of ultrasound search relative to searches for X-ray and MRI technologies by aggregating search intensities for these terms for each state and year. Examples of search indices we use include: (ultrasound + sonography)/x-ray, (ultrasound + sonography)/MRI, ((ultrasound + sonography)/x-ray)^2, ((ultrasound + sonography)/MRI)^2, log ((ultrasound + sonography)/x-ray), among others.

We use search volumes for the English terms (ultrasound) instead of relying on local language specific queries for two reasons: 1) the language of medical practice and medical technologies in India is English and searches for medical technologies are consequently likely to be in English; 2) existing demographic literature suggests that educated groups, who are also likely to be English speaking, are more likely to access ultrasound and practice prenatal sex selection (Guilmoto, 2015).

Python's 'pytrends' package[4] allowed us to quickly and efficiently retrieve data by interacting with the Google Trends API. Since Google calculates its search volume index by a sampling method, results can vary day to day. To help account for this, we average our yearly measures for the search indices over four collection days (4/1/17, 5/1/17, 6/1/17, and 7/1/17). Also, due to privacy concerns, Google does not report data for low volume queries. Consequently, while higher volume states have consistent volume over collection days, some low volume states (e.g. Bihar, Jharkhand, Chattisgarh) fluctuate much more.

For sex ratios, we rely on two data sources. The first is the child sex ratios (CSR) from the Census data of 2011.[5] These are highly correlated with the SRB

[4] `https://pypi.python.org/pypi/pytrends/`

[5] The data from the CSR are extracted from the website `http://www.indiastat.com/default.aspx`.

and a good proxy measure of prenatal sex selection particularly in states where birth registration systems are deficient. Child sex ratios are more widely available for different states. For the civil registration data, we rely on SRB time series from 2011 to 2014 by state for high (over 90%) birth registration states (ORGI, 2016).

5.4 Results

5.4.1 Search Indicators and Sex Ratios

Search intensity for ultrasound is higher in states with higher, more distorted (masculine) sex ratios. This relationship holds when examining the correlation between ultrasound search and SRB data pooled from 2011-2014 for high birth registration states, as shown in Figure 5.4, and also for ultrasound search and the 2011 CSR as shown in Figure 5.5.

In both these figures, (ultrasound + sonography) search intensity is measured as the log ratio of the search volume for (ultrasound + sonography) and x-ray and the log ratio of (ultrasound + sonography) and MRI. In Figure 5.4 each data point represents a state-year (n = 11, T = 4, nT=44).

The correlation between ultrasound-related search indicators normalised against X-ray and MRI volumes and 1) CSR from the Census 2011 (n = 22); 2) SRB from civil registration for 2011 to 2014 are summarised on Table 5.1. Search indicators for ultrasound normalised against x-ray show a stronger, statistically significant correlation with both civil registration SRBs and child sex ratios as compared to ultrasound search normalised against MRI searches.

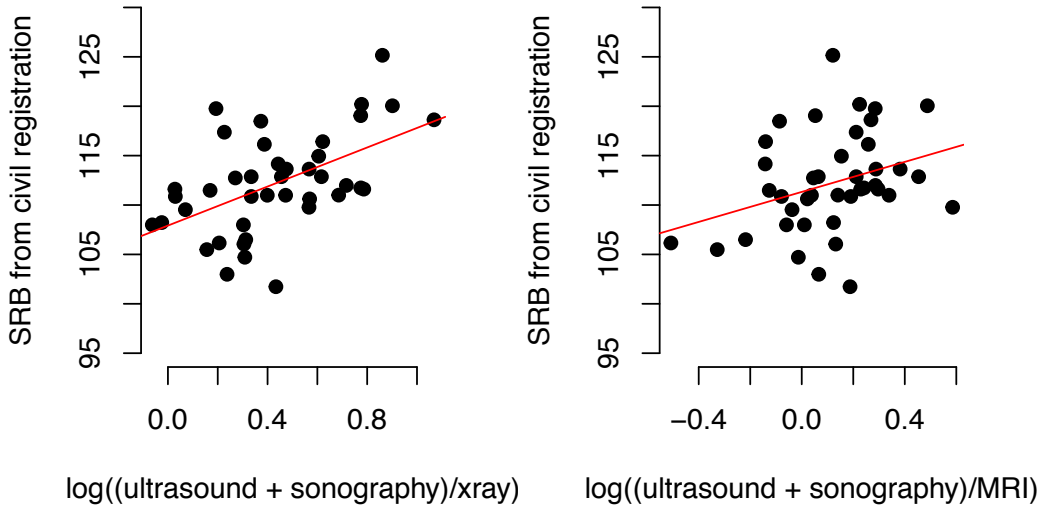


Figure 5.4: Search intensity for ultrasound normalised by x-ray (ultrasound/xray (log)) (left panel) and by MRI (ultrasound/mri (log)) (right panel) plotted against sex ratio at birth (SRB) data, 2011-2014, from high birth registration states. Data are from n=11 states for T=4 years.

Table 5.1: Correlation coefficients between Google search volumes for: 1) ultrasound/xray (log) search indicator; 2) ultrasound/MRI (log) search indicator and 1) Census 2011 child sex ratios by state; 2) SRB by states 2011 to 2013.

	ultrasound/xray (log)	ultrasound/mri (log)
child sex ratio	0.67***	0.38*
sex ratio at birth	0.53***	0.33**

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

5.4.2 Between and Within State Variation

We next fit between and within-state regression models to examine whether ultrasound-related search volumes can capture both variation across Indian states in the SRB as well as temporal trends in the SRB. In one pair of models, we use log((ultrasound + sonography)/x-ray) as the predictor variable, and in the second pair of models, we use log((ultrasound + sonography)/mri) as the predictor. Log(SRB) is the outcome in all models. The overlap between available SRB data

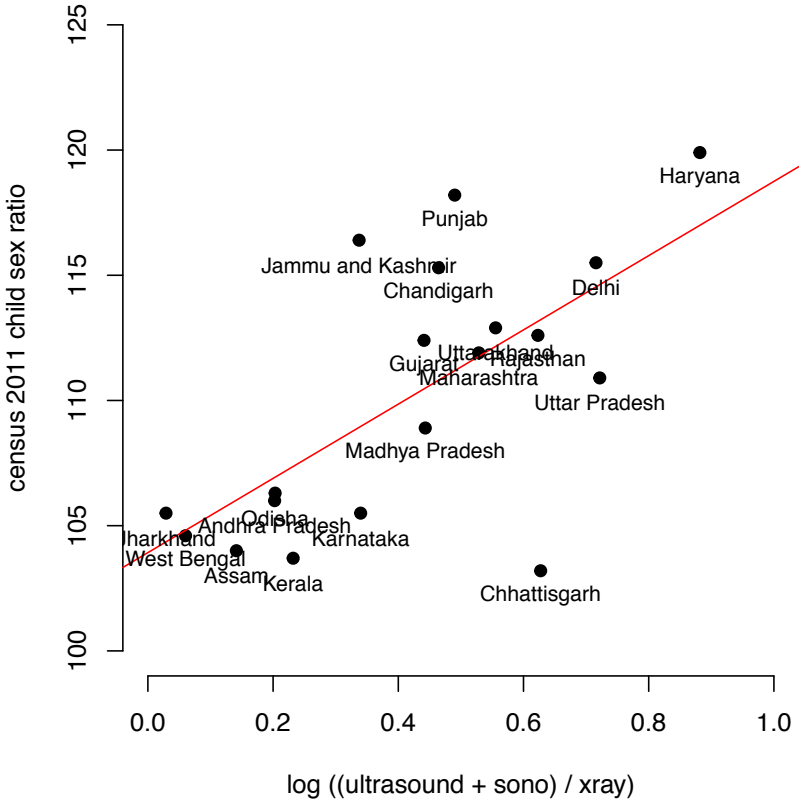


Figure 5.5: Ultrasound/xray (log) search intensity indicator from 2011-2015 and child sex ratios from 2011 Indian Census.

and Google search data are restricted from 2011, when the geo-coding of Google Trends was improved, until 2014, which is the most recent year for which SRB data are available. These results are reported in Table 5.2. These models indicate that the ultrasound search indicators capture between-state variation in the SRB. For 2011-2014, a 1% increase in the search indicator corresponded to 11% higher SRB levels. The search indicators are less successful at capturing temporal trends within states.

5.4.3 Now-casting the SRB

As the results presented above indicate, ultrasound-related search indicators capture between-state variation in the SRB well. Can state-level variations in Google

Table 5.2: Between and within-state regression models predicting log SRB as an outcome of: 1) ultrasound/x-ray (log) search indicator; 2) ultrasound/MRI (log) search indicator.

	Between	Within
ultrasound/xray (log)	0.11**	0.01
	(0.04)	(0.03)
ultrasound/mri (log)	0.17*	-0.02
	(0.07)	(0.02)

* p < 0.1; ** p < 0.05

search intensity for ultrasound also help predict, or now-cast, the SRB? For this prediction, we use three training regression models that have the state-level SRB data from 11 high birth registration states pooled for 2011, 2012 and 2013 (n = 33) as the outcome variable.[6] Each unit observation corresponds to a state-year SRB value. The predictors used in the three models are: 1) search data only: using data on Google search indicators for ultrasound normalised by x-ray and MRI search volumes at the state level for 2011, 2012, and 2013; 2) lag models only: using a lagged variable model, in which we use 1-year lag and 2-year lag SRB values as the predictor variables; 3) lag and search combined model: using both lagged SRBs and Google search data as predictor variables. From these three training models that are fitted on data from 2011–2013, we make an out-of-sample prediction for the 2014 state-level SRB for which civil registration data are available. The prediction equation takes the form of a multiple regression:

$$y_i = \beta_0 + \beta_1 x_{i1} + ...\beta_j x_{ij} + e_i \tag{5.1}$$

where y_i refers to the SRB for a state in a given year (e.g Delhi in 2012), x_i is the value of (j) predictor variables (e.g different search indicators for ultrasound intensity such as (ultrasound + sonography)/x-ray, ((ultrasound + sonography)/x-ray)^2 for Delhi in 2012 for the search only model, or SRB val-

[6]Goa is a high birth registration state for which we have SRB data. The Google search indicators for Goa for the period between 2011 and 2013 are erratic. The search indicators are much stabler for more recent periods starting 2014-2016.

ues for Delhi in 2011 (lag 1) and 2010 (lag 2) for the lagged variable only model), $\beta_{1,2..k}$ are the regression coefficients estimated for the predictor variables, β_0 is the intercept and e_i is the error term.

To optimise future predictions from the models, all three regression models are estimated with LASSO (least absolute shrinkage and selection operator) that is a penalised regression approach for variable selection and prediction purposes (Tibshirani, 2011; Friedman et al., 2001). In addition to minimising the residual sum of squares as in the least squares estimator, the LASSO estimator regularises the sum of coefficients $\sum_{j=1}^{p} |\beta_j|$ by a penalty term λ as shown in Eq. 5.2.

$$\text{Minimise: } \sum_{i=1}^{n} (Y_i - \sum_{j=1}^{p} X_{ij}\beta_j)^2 + \lambda \sum_{j=1}^{p} |\beta_j| \tag{5.2}$$

We estimate λ with leave leave-one-out cross validation, and for each of the three models, we choose the value of λ that gives the sparser, most regularised model such that the error is within one standard error of the minimum. For the search only model, the two search indicators that are retained by the LASSO are ((ultrasound + sonography)/x-ray)^2 and log(ultrasound + sonography + x-ray). Predictions from the three models are reported in Table 5.3. We present results from the high birth registration states first, as SRB data from these states are more reliable and enable us to assess how well Google search based SRB estimates for 2014 perform when compared to official published statistics for the same year. As discussed earlier, these states are generally wealthier and are also have better internet diffusion. Google search volume for these states is also more stable in these states.

As the table shows, performance as measured by root mean squared error (RMSE) when predicting the 2014 SRB is best for the Google search based prediction. For within-sample prediction for 2011-2013 SRBs, the lag model performs best. However, the lag model under-predicts the SRB in 2014 for Haryana and most significantly for Rajasthan (114.1 instead of 125 reported in official statis-

Table 5.3: Sex ratio at birth (SRB) 2014 for 11 high birth registration states as reported in official statistics of civil registration (column 2), and as predicted by LASSO with lagged (lag 1 and lag 2) SRB values and Google search (column 3), Google search only (column 4), and lagged (lag 1 and lag 2) SRB only (column 4). Root mean squared errors for each of the three models are reported at the bottom.

State	SRB 2014	Lag + Search	Search only	Lag only
Chandigarh	114.9	111.8	114.4	111.8
Delhi	111.6	112.1	112.5	112.1
Gujarat	112.9	111.5	111.2	111.4
Haryana	118.6	115.1	119.6	115.7
Karnataka	108.0	108.8	109.7	108.2
Kerala	105.5	109.2	109.7	108.7
Maharashtra	109.8	111.6	109.9	111.5
Odisha	113.6	112.0	114.9	112.0
Punjab	113.6	113.7	113.9	114.0
Rajasthan	125.2	113.7	118.1	114.1
West Bengal	111.5	110.6	110.6	110.3
Root mean squared error		3.9	2.9	3.8

tics). In Rajasthan, official statistics report a significant jump between 2013 to 2014 in the SRB from 116 male births for 100 female births to 125 in 2014. The Google search based prediction of the SRB is better aligned with the civil registration estimates than the lagged model predictions. Search intensity for ultrasound in 2015 and 2016 for Rajasthan and Haryana is lower than in 2014. The predicted SRBs for 2015 and 2016 based on Google search data suggest that the SRB will decline in both states. Similar declines in the SRB for 2015 and 2016 are also predicted in Delhi compared to 2014 SRB levels. Search based predictions of the 2015 and 2016 SRB levels for Indian states are reported in Table 5.5. Official SRB statistics for 2015 and 2016 are not available as yet.

Table 5.4 presents predicted values of the 2014 SRB for low birth registration states. The RMSE reported in the model measures model performance compared with the published official statistics (reported in column 2 of the Table). It should be noted that official statistics for the SRB are less reliable in these states due to lower coverage of birth registration systems. For most of these states, all three

Table 5.4: Sex ratio at birth (SRB) 2014 for low birth registration states as reported in official statistics of civil registration (column 2), and as predicted by LASSO with lagged (lag 1 and lag 2) SRB values and Google search (column 3), Google search only (column 4), and lagged (lag 1 and lag 2) SRB only (column 4). Root mean squared errors for each of the three models are reported at the bottom.

State	SRB 2014	Lag + Search	Search only	Lag only
Andhra Pradesh	104.7	108.2	109.5	107.6
Assam	110.9	111.8	111.9	111.8
Chhattisgarh	107.1	111.0	111.4	110.6
Jharkhand	112.9	113.2	111.3	113.4
Madhya Pradesh	110.1	111.1	112.5	111.0
Tamil Nadu	119.9	113.1	108.9	113.2
Uttar Pradesh	113.5	111.5	116.6	111.4
Uttarakhand	115.6	114.7	113.5	115.1
Root mean squared error		3.1	4.8	3.0

models show higher SRB estimates than those reported in official statistics for 2014. In general, the now-casts generated by Google search alone do worse than those by the lagged model, which performs best. This is perhaps not surprising given that a number of these states, as noted earlier, are among the poorest in India (e.g.Chattisgarh and Jharkhand) where Google search volumes are also low, and consequently, erratic. The search-based prediction for Tamil Nadu increases the RMSE significantly. Ultrasound search intensity for Tamil Nadu remains relatively low and does not capture the upward trend that has been reported in its SRB levels in official statistics.

5.5 Conclusion

Our study suggests that Google search intensity for ultrasound captures between-state variation in sex ratio indicators well. Within-state temporal trends appear to be harder to track, partly limited by the fact that overlapping data for both indicators are available from 2011 to 2014. Drawing on between-state variation from 2011 to 2013 in Google ultrasound search intensity and the SRB, we now-cast

Table 5.5: Google search predicted sex ratio at birth (SRB) for 2015 and 2016 for Indian states.

State	2015	2016
High Birth Registration States		
Chandigarh	114.9	116.1
Delhi	112.5	112.0
Gujarat	112.1	113.2
Goa	108.0	109.6
Haryana	116.3	116.3
Karnataka	110.9	111.1
Kerala	110.1	110.2
Maharashtra	111.6	114.0
Odisha	112.4	115.5
Punjab	116.8	115.6
Rajasthan	114.7	114.1
West Bengal	110.3	110.6
Low Birth Registration States		
Andhra Pradesh	110.0	111.5
Assam	111.8	114.4
Chhattisgarh	112.9	
Jharkhand	112.1	112.3
Jammu and Kashmir	112.0	109.5
Madhya Pradesh	112.7	113.4
Tamil Nadu	108.9	109.1
Uttar Pradesh	114.0	113.6
Uttarakhand	116.4	

the out-of-sample 2014 SRB, for which official data were recently published. For the richer states with high birth registration as well as higher internet diffusion, we find that Google search predicts their SRB in 2014 better than a lagged variable model. For low birth registration states where SRB data are less reliable and search data are also more erratic, Google search based prediction does reasonably well but underperforms when compared to the SRB lagged model.

These results point to the potential role that Google search data can play in indirect demographic estimation and to track real-world demographic indicators for which official data sources such as Census or civil registration data are sometimes deficient or slow to be released. By studying a population's search footprint and tracking interest in an essential factor (ultrasound) leading to a

macro-demographic phenomenon (SRB distortions), we show how real time data can be used to study behaviours that are not readily measurable. Moreover, we highlight different ways in which these data can be used. First, as a potential benchmarking tool to examine if search behaviour also tracks spikes that are seen in official demographic estimates. This is especially meaningful for indicators such as the SRB that can often be erratic across years. Google search can be a potential tool to determine whether these trends may in fact reflect changing behaviours rather than data inconsistencies or measurement errors alone, especially as the internet diffuses more widely in countries such as India. Second, this study highlights the potential role that Google search can contribute to developing real-time now-casts of demographic estimates, particularly in developing world settings where these data are slow to come out but policy interest in tracking them is high. A number of demographers have speculated that prenatal sex selection may spread to new areas of the world (e.g. sub-Saharan Africa) as ultrasound diffuses there (Bongaarts, 2013). Google search may allow us to track this, perhaps before demographic statistics do.

Part III

Prenatal Sex Selection and Postnatal Excess Female Mortality

Chapter 6

A Macro-demographic Study of Fertility and Mortality Changes in Child Sex Ratios in Comparative Perspective

6.1 Introduction

Parts I and II of this thesis have addressed prenatal sex selection as indicated by sex ratio at birth (SRB) distortions. Part III focuses on both prenatal and postnatal manifestations of son preference.[1] Prior to the availability of sex detection technologies such as ultrasound, postnatal manifestations of son preference in the form of excess female mortality in infancy and childhood had been widely documented in the demographic literature, particularly for the countries of South Asia. More recent, global analyses have found that excess female mortality in infancy and childhood remain prevalent, most prominently in South Asia, but also in the Middle East and parts of Africa (Alkema et al., 2014; Sawyer, 2012). The notion of excess implies that girls experience higher than biologically expected mortality on account of both direct or indirect forms of gender discrimination, which, as prominently described by Amartya Sen, results in them being 'missing' from population structures (Sen, 1990). Excess mortality may result directly

[1] A modified version of this chapter is forthcoming as an article, Kashyap, R. "Does prenatal sex selection substitute excess female child mortality?" in *Population Studies*.

from infanticide or from the unequal allocation of healthcare and nutrition to girls within families (Jayachandran and Kuziemko, 2011; Borooah, 2004; Li et al., 2004; Arnold et al., 1998; Gupta, 1987; Miller, 1987). Excess mortality may also indirectly emerge from the fertility effects of son preference. Sex-differential stopping behaviour (DSB) practiced by parents desiring a boy cause girls to be born into larger families compared to boys (Basu and De Jong, 2010; Clark, 2000). Through this indirect mechanism, within-family differences might not be apparent between girls and boys but instead aggregate-level gender gaps are likely to emerge if net resources per child are fewer in larger families than smaller ones (Jain, 2014; Barcellos et al., 2014; Rosenblum, 2013; Choe and Kim, 1998).

As the discussion above illustrates, the preconditions underlying prenatal and postnatal manifestations of son preference are different. Postnatal excess female mortality is more likely to occur in populations where norms for larger family sizes prevail and families practice DSB to achieve their son preference. Here, mortality differentials resulting from high fertility behaviour are likely to emerge. Prenatal sex selection on the other hand is likely to be practiced in societies where parents prefer to keep their families small by practicing abortion instead of proceeding to additional births, and ultrasound is more widely available. Consequently, the relative demographic contribution of prenatal and postnatal manifestations of son preference to missing girls in the population is likely to vary by the stage of the demographic transition that a population is in.

Changes in prenatal sex selection may also influence changes in postnatal excess female mortality. If an important factor underlying postnatal excess mortality is child unwantedness, the increasing adoption of sex-selective abortion may plausibly imply better survival chances for those girls who are born as they are more likely to be wanted (Goodkind, 1996). An emerging literature has empirically tested what Goodkind called the substitution hypothesis. This literature has adopted different approaches and shown mixed results. Drawing on birth

registration data in Taiwan, Lin et al. (2014) found evidence in favour of substitution, where abortion legalisation in 1985 in a country where ultrasound was already available, led to faster improvements in female neonatal survival relative to males for higher parity births. For India, evidence has been mixed. Hu and Schlosser (2015) found that birth cohorts experiencing prenatal sex selection as indicated by distorted sex ratios witnessed faster reductions in malnutrition rates for girls relative to boys, but found no statistically significant evidence for faster reductions in mortality for girls. The authors exploited variation in census child sex ratios by birth year within states. In contrast Anukriti et al. (2016), found evidence for faster reductions in mortality for a subset of girls. Drawing on data on the imports of ultrasound scanners at the national level, the authors categorised ultrasound access into three periods – a pre-ultrasound period (1973–1985), early diffusion period (1985–1994) and late diffusion period (1995–2005). Second- and higher birth order girls had around 2% higher risk of post-neonatal mortality than girls with first-born brothers. The authors found that this mortality gap was eliminated in the periods when ultrasound became available in India.

In contrast to these country-specific analyses that have sought to identify the impact of sex-selective abortion, either via liberalised abortion or access to ultrasound, on excess female mortality, studies such as Bongaarts and Guilmoto (2015) and Goodkind (1996) have adopted descriptive and wider geographical approaches. Goodkind examined macro-level correlations between male-to-female SRB levels and male-to-female infant and child mortality ratios for the same period from the 1970s to early 1990s across several East Asian countries. He found evidence suggestive of substitution between prenatal sex selection and postnatal excess mortality in South Korea, but no such pattern in China. Using measures from the same period might not capture the interrelated dynamics of the two processes, however. Improvements in relative survival for the the birth cohorts affected by prenatal sex selection as they move past infancy and childhood would

only be visible one- to five-years later and not in the same period if substitution is occurring. Furthermore, examining changes in sex ratios of mortality is not sufficient to detect whether prevailing mortality levels indicate excess female mortality, and whether changes in mortality ratios are aligned with expected patterns of mortality change. This is an important consideration because sex ratios of infant and child mortality have been shown to change with mortality decline (Alkema et al., 2014; Sawyer, 2012).

More recently, Bongaarts and Guilmoto (2015) have presented global estimates of the contribution of prenatal versus postnatal discrimination to missing women since the 1970s using United Nations World Population Prospects (UN WPP) (2012) data. In contrast to Goodkind's analysis, they explicitly adopted a reference standard to generate expected sex ratios of mortality at different levels of overall mortality and from these, derived estimates of absolute numbers of excess female deaths. They found that the contribution of prenatal discrimination to newly missing women in the world has increased since the 1980s, while the contribution of postnatal discrimination has shown small declines since the 1990s. While Goodkind measured mortality change in terms of sex ratios of child mortality, Bongaarts and Guilmoto's focused on excess deaths at all ages and computed absolute contributions of prenatal and postnatal discrimination to the total numbers of missing women in each five-year period. The contributions of numbers of excess female deaths to total missing women however might plausibly decline as a consequence of improving overall mortality conditions and declining death numbers. Both relative and absolute measurements of excess mortality are helpful to assess improvements in female survival relative to male survival.

Part III of this thesis contributes to the literature tackling the relationship between prenatal sex selection and postnatal excess mortality in two studies that adopt different methodological approaches and sources of data. Both studies address whether the rise and spread of prenatal sex selection has substituted

postnatal excess mortality of girls in countries where excess female mortality has been prevalent. The two studies interpret the hypothesis of substitution in two slightly different ways. First, in a macro-demographic perspective, substitution can be thought to imply a greater demographic contribution of prenatal sex selection to missing women or distorted sex ratios accompanied by reductions in postnatal excess mortality as countries proceed along the path of demographic modernisation. This approach to substitution is implicit in studies such as Bongaarts and Guilmoto (2015). Chapter 6 in part III adopts a macro-demographic approach to examine the contributions of prenatal and postnatal dynamics to changes in child sex ratio using lifetable decomposition methods applied to UN WPP 2015 country-level lifetable data (United Nations, 2015a). This approach highlights how the contributions of each component vary over time and across countries, as well as how changes in prenatal sex selection are associated with changes in excess female mortality within countries. Examining associations between the prenatal and postnatal, however, cannot clarify whether increases in prenatal sex selection have influenced changes in girls' mortality relative to boys.

In this second sense, substitution can be thought to occur if increases in prenatal sex selection, either via the availability of abortion or increasing access to ultrasound, may also reduce patterns of female disadvantage in mortality, as distinct from the other modernisation processes such as weakening son preference norms that could independently cause mortality change. This definition of substitution is implicit in studies such as Lin et al. (2014), Hu and Schlosser (2015) and Anukriti et al. (2016). These studies use micro-level data in the form of birth histories and econometric strategies to exploit variations over birth years in access to prenatal sex selection to estimate the impact of prenatal sex selection on mortality change. Chapter 7 in part III follows a similar approach using birth histories from the Demographic and Health Surveys. In this study, I assess the impact of prenatal sex selection on changes in girls' mortality relative to boys,

as well as on patterns of disadvantage in female mortality, in six countries where SRB distortions have emerged.

The rest of this chapter is organised as follows: first, I discuss how prenatal and postnatal manifestations of son preference are likely to shift with demographic modernisation, and hypothesise how the pace of prenatal substituting the postnatal might vary at different stages of the transition. I then develop a methodological setup to measure the dynamics of substitution. I present results of the analysis by focusing on countries that experienced outlying levels of change in both the postnatal (mortality) and prenatal (fertility) components of their child sex ratio trajectories. I conclude with a discussion of patterns observed.

6.2 Theoretical Framework

6.2.1 Prenatal and Postnatal Mechanisms

Prenatal sex selection provides parents with strong son preference a more effective means to implement their preference than relying on differential stopping rules alone. In the absence of prenatal sex selection, parents must rely on contraceptive use to stop childbearing when they bear a son. Differential stopping rules however cannot guarantee the parity at which parents bear a son, and parents relying on stopping rules may consequently have several unwanted daughters before realising their son preference. Studies from South Asia show how son preference results in daughters being born into larger families (Basu and De Jong, 2010; Clark, 2000). Within these families, not all daughters are unwanted. It is later-born daughters born at parities three or higher without surviving brothers who show the worst outcomes in mortality (Pande, 2003; Arnold et al., 1998; Choe et al., 1995; Muhuri and Preston, 1991; Gupta, 1987).

The mechanisms and levels of excess female mortality are likely to vary at different stages of the demographic transition. In societies at an early stage of

the demographic transition with high mortality and fertility, low incomes and resource constraints, parents are likely to implement their son preference through postnatal discrimination in the form sex-selective allocation of resources (Bongaarts, 2013). However, even as the transition proceeds and parents have greater access to contraception, postnatal excess mortality for girls may emerge indirectly from the fertility effects of son preference. In this mechanism, while within-family differences for girls and boys may be small, the indirect effects of fewer resources per capita available in larger families in which girls are more likely to be born compared with smaller ones result in aggregate-level distorted sex ratios of mortality (Jain, 2014; Barcellos et al., 2014; Rosenblum, 2013).

It is plausible that better control of fertility implies lower levels of excess mortality for girls, and thus, the contribution of excess mortality to missing women is likely to be higher in early-transition societies with higher mortality and fertility than mid- to late-transition ones. A better control of fertility in societies with son preference may come about through different channels involving either the weakening of son preference or the uptake of sex-selective abortion to reduce fertility whilst realising son preference.

Existing literature suggests that demographic modernisation entails the weakening of son preference (Chung and Das Gupta, 2007a; Bhat and Zavier, 2003). At early-transition stages, son preference is likely to be high and stable, whereas in mid- to late-transition stages, son preference is likely to be moderate to low, and declining (Bongaarts, 2013). Despite weaker and declining son preference in mid- to late-stage populations, for example South Korea in the 1980s and early 1990s, the swift diffusion of ultrasound in more modernised, richer contexts alongside the spread of small family norms are likely to result in increasing prenatal sex selection as indicated by steep rises in macro-level SRB trajectories (Kashyap and Villavicencio, 2016). In contrast, despite more widespread son preference norms, countries like India that are at an earlier stage of demographic modernisation

are likely to have flatter SRB trajectories and less peaked SRB levels, suggestive of more heterogeneous access to prenatal sex testing technology and higher overall fertility levels respectively (Kashyap and Villavicencio, 2017). Figure 6.1 shows how SRB levels vary with the total fertility rate (TFR) across some of the countries where SRBs have become distorted. The figure highlights how SRB levels are generally lower and SRB trajectories flatter at higher fertility levels that would be expected in early- to mid-transition societies (e.g India or Vietnam), and SRBs begin to rise steeply as fertility falls from mid- to late-transition stages.

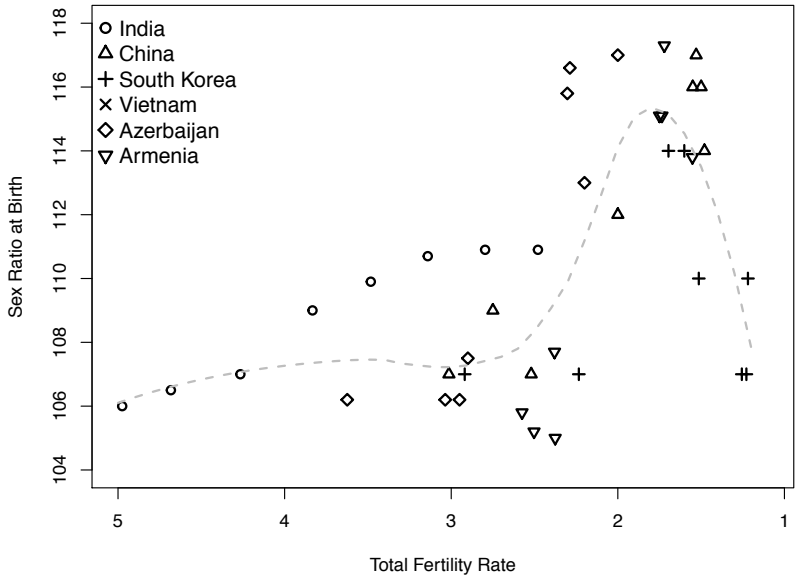


Figure 6.1: Total fertility rate and sex ratio at birth (number of male births/100 female births), select countries, 1975 to 2015. Data from United Nations (2015a). Grey dashed line shows a locally weighted least squares smoother applied to the data.

The above discussion suggests that we should expect the relative contribution of prenatal sex selection compared to postnatal excess mortality to distorted sex ratios in populations with son preference to increase as societies experience demographic modernisation. Across different countries where SRB distortions have been noted, SRB trajectories show common patterns resembling a diffusion process, involving an initial rise followed by a process of levelling off (Guilmoto, 2009).

Simulation studies presented in part I of this thesis indicate that this levelling off phase is likely to occur when ultrasound diffusion is complete and low fertility norms become widespread (Kashyap and Villavicencio, 2017, 2016). As son preference continues to weaken and populations move further into an advanced, or a post-transition stage with very low fertility levels, SRBs are likely to show improvements and an eventual return to normal values (Bongaarts, 2013). As is indicated in Fig. 6.1 this turnaround has already been witnessed in South Korea (Chung and Das Gupta, 2007a) and there is evidence for incipient turnarounds in SRBs in China and India (Das Gupta et al., 2009).

6.2.2 Hypotheses

At the macro-level, the substitution hypothesis pertains to relative changes in prenatal sex selection and postnatal excess female mortality over time. Substitution would be suggested if, in contexts with prevailing postnatal excess female mortality, increases in masculinity in SRBs are associated with faster declines in mortality for girls relative to boys. As noted previously, observing such a macro-level pattern would not however conclusively indicate that sex-selective abortion were causing changes in sex-differentials in mortality. Wider modernisation processes, such as the weakening of son preference norms, could independently cause faster improvements in mortality for girls relative to boys. Changes in excess female mortality may even plausibly precede changes in SRBs.

When discussing substitution, I will adopt two slightly different interpretations of the term. First, following from discussions in the previous section, I will refer to how prenatal sex selection might come to substitute postnatal excess mortality in terms of its demographic contribution to distorted sex ratios at different stages of the demographic transition. Second, I will discuss when and where we might expect changes in prenatal sex selection to cause changes in postnatal excess mortality.

In terms of its demographic contribution to distorted sex ratios, prenatal sex selection is likely to substitute postnatal excess mortality swiftly in populations at mid- to late-stages of the demographic transition. In these contexts, son preference is less widespread and likely weakening rapidly, and levels of excess female mortality are also likely to be low. Swift technology diffusion amidst already low and declining total fertility levels is likely to enable increases in prenatal sex selection. East Asian populations such as South Korea or Taiwan, and the Caucasus countries of Armenia, Azerbaijan, Georgia exemplify such populations.

The substitution of postnatal excess mortality by prenatal sex selection in underpinning distorted sex ratios is likely to be slower in early- to mid-transition populations with stronger and widespread son preference norms that are weakening slowly, as suggested by high prevailing levels of excess female mortality. In these less developed contexts, more gradual or heterogenous diffusion of prenatal sex testing technology combined with higher fertility norms plausibly result in a slower population-wide uptake of prenatal sex selection. The South Asian countries of India, Pakistan and Nepal, or East Asian contexts such as China, would be examples where excess female mortality levels are high and would be expected to change slowly even as SRBs begin to rise. Son preference may also be more widespread across different social groups in these settings. For example, in northwest India, son preference has been reported in both Hindu and Muslims populations (Guilmoto, 2015). Sex-selective abortion, however, may not be equally practiced by both despite availability of ultrasound due to differential religious taboos against abortion. More widespread son preference combined with social variations in methods to implement it would suggest the persistence of excess female mortality accompanying gradual population-level increases in prenatal sex selection.

Prenatal sex selection may have greater impact on reducing in excess female mortality in societies where son preference levels are widespread and more stable,

and its mortality manifestations in patterns of female disadvantage in mortality are also widespread. This is plausible in mid-transition stages in populations than when the transition is nearly complete and son preference is likely weaker and the mortality manifestations of son preference are less widespread. For postnatal excess mortality levels to change directly in response to prenatal sex selection, populations adopting prenatal sex selection must overlap with those where postnatal manifestations are otherwise present. More significantly distorted SRBs have often been observed among urban, educated and wealthier groups, at least initially when SRBs began to rise (Guilmoto, 2015; Jha et al., 2011). In their study of South Asia, Monden and Smits (2013) found that patterns of female disadvantage in child mortality were concentrated among less educated mothers. If prenatal and postnatal manifestations of son preference remain socially stratified, this would indicate that changes in SRBs would remain unrelated to changes in mortality. However, as ultrasound and low fertility norms gradually diffuse across the population to less privileged social groups where disadvantage in female mortality prevails and son preference is strong, prenatal sex selection may drive changes in mortality by enabling parents to better target the desired sex composition of children. An empirical examination of patterns of differential sorting into prenatal and postnatal mechanisms and its implications for the impact of prenatal sex selection on patterns of disadvantage in female mortality is undertaken in the next chapter of this thesis.

In the discussion above, it is assumed that postnatal excess mortality exists prior to the onset of prenatal sex selection in the population. Postnatal excess mortality and prenatal sex selection may simultaneously appear and reinforce each other if conditions result in the emergence or intensification of son preference. For example, in the Caucasus, some scholars have suggested that protracted civil conflict in the Azerbaijan and Armenia may have led to the resurgence of patriarchy and reinforced the preference for sons (Michael et al., 2013). Others

have also pointed to the role of widening gender inequalities after independence from the Soviet Union as intensifying the preference for sons (Duthé et al., 2012).

6.3 Data and Methodology

6.3.1 Child Sex Ratios

A key requirement to analyse substitution is to be able to follow male and female cohorts separately to distinguish the effects of prenatal sex selection and postnatal child survival on the composition of the cohort at a specific age. Once this population can be approximated separately for each sex, the ratio of male-to-female survivors or in other words the sex ratio can be estimated. The UN WPP is a global and harmonised database that provides the relevant demographic estimates in the form of period lifetables, birth counts and SRBs for five-year periods (e.g 1980–1985, 1990–1995, etc.) to be able to approximate age and sex population composition (United Nations, 2015a). Limitations of the UN WPP data are noted in the appendix to this chapter. The UN WPP data are available for five-year periods and for five-year age intervals. With these data, the population sex ratio after infancy and early childhood that is most readily estimated is the sex ratio of 5–10 year olds. Throughout the chapter, I term this population sex ratio of 5–10 year olds the child sex ratio (CSR).

As shown in Fig. 6.2, the population of survivors between the ages [5, 10) for the period [t, t+5) can be visualised as the ${}_5L_5$ parallelogram in the age-cohort lexis surface, which indicates the cohort of survivors from the birth cohort born five-years before in the period [t-5, t). Cohort lifetable data are not readily available for all countries, however, to be able to track actual cohort survivorship. With available period data, the survivors between the ages of 5 and 10 in the population can be approximated from the synthetic cohort of survivors from the

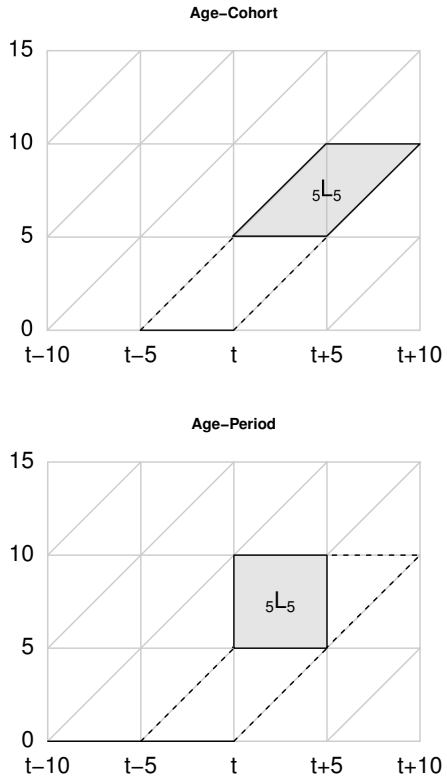


Figure 6.2: Population aged 5 to 10 in age-cohort and age-period perspectives.

period life table, as indicated in the ${}_5L_5$ square in the age-period surface in Fig. 6.2.

The child sex ratio between time [t, t+5) of [5, 10) years olds, $CSR^{5-10}_{t,t+5}$, can be written as:

$$CSR^{5-10}_{t,t+5} \equiv \frac{P^{5-10}_{m,t,t+5}}{P^{5-10}_{f,t,t+5}} \equiv \frac{B_{m,t-5,t}}{B_{f,t-5,t}} \times \frac{\frac{l_5^{m,t,t+5}}{l_0^{m,t,t+5}}}{\frac{l_5^{f,t,t+5}}{l_0^{f,t,t+5}}} \times \frac{\frac{{}_5L_5^{m,t,t+5}}{l_5^{m,t,t+5}}}{\frac{{}_5L_5^{f,t,t+5}}{l_5^{f,t,t+5}}} \tag{6.1}$$

where $P^{5-10}_{m,t,t+5}$ refers to the male population of 5–10 year olds (excluding those who have completed 10 years) for time [t, t+5) and $P^{5-10}_{f,t,t+5}$ the female population of 5–10 year olds for the same time period, $B_{m,t-5,t}$ indicates the male births and $B_{f,t-5,t}$ female births for [t-5, t). The following quantities are derived from the male and female lifetables as indicated by the superscript m or f respectively:

$l_5^{t,t+5}$ refer to the lifetable survivors until age 5, $l_0^{t,t+5}$ the lifetable radix, ${}_5L_5^{t,t+5}$ to the person-years lived between the ages of 5 and 10.

As $l_0^{m,t,t+5} = l_0^{f,t,t+5}$ and the ratio of male births to female births ($\frac{B_{m,t,t-5}}{B_{f,t,t-5}}$) is the sex ratio at birth (SRB), the CSR in eq. (6.1) can be simplified to,

$$CSR_{t,t+5}^{5-10} \equiv \underbrace{SRB_{t-5,t}}_{\text{fertility component}} \times \underbrace{\frac{{}_5L_5^{m,t,t+5}}{{}_5L_5^{f,t,t+5}}}_{\text{mortality component}} \tag{6.2}$$

As shown in eq. (6.2), the CSR can be expressed as the product of two components: the *fertility* component that refers to the sex ratio at birth $SRB_{t,t-5}$ and the *mortality* component that captures the ratio of male to female person-years lived between the ages of 5 and 10 for those who survived until age 5 $\frac{{}_5L_5^{m,t,t+5}}{{}_5L_5^{f,t,t+5}}$ in the lifetable population.

The two quantities required to calculate the CSR in eq. (6.2) can be derived from the SRB time-series and the person-years from the period lifetables available in the UN WPP database. I compute $CSR_{t,t+5}^{5-10}$ for all 171 countries for four time-periods – 1980–1985, 1990–1995, 2000–2005, 2010–2015 – as well as changes in CSRs and its two components across countries to assess countries with distinctive, outlying trajectories. After dropping regional geographical units, the dataset contains 201 countries. 30 countries with populations under one million are dropped due to small numbers and erratic fluctuations in their sex ratio quantities. By analysing patterns of change in the prenatal (fertility) and postnatal (mortality) component across consecutive decades for the synthetic cohort, it is possible to assess if, as predicted by the substitution hypothesis, increasing masculinity of birth cohorts was offset with faster improvements in relative survivorship for females.

6.3.2 Quantifying Anomalous Change

Once CSRs, their relative components and changes in their relative components are calculated, I analyse whether fertility or mortality components are anomalous. I quantify missing female births and excess female deaths that underlie the distorted ratios for each period (1980–1985, 1990–1995, 2000–2005, 2010–2015).

Prenatal: Missing Births

Natural variations in the SRB have been documented, with low SRBs reported in sub-Saharan Africa and higher SRB levels reported in Asian populations (Klasen and Wink, 2003; Garenne, 2002). Despite these natural variations, the steady increase in the SRB within a time span of a decade since the 1980s or 1990s in several countries attributable to the practice of sex-selective abortion has been widely documented in the demographic literature (Guilmoto, 2015; Frost et al., 2013; Michael et al., 2013; Duthé et al., 2012; Guilmoto, 2009; Chung and Das Gupta, 2007a; Arnold et al., 2002). Prior to the 1980s before the diffusion of accurate and early ultrasonography that has allowed for the determination of foetal sex, the impact of prenatal sex selection was limited (Guilmoto, 2009). To estimate missing female births resulting from prenatal sex selection I compare female birth estimates for the period of interest with female births that would have resulted holding the SRB at the country's 1970–1975 levels before ultrasound technology became widely available.

The missing female births in the child sex ratio ($CSR^{5-10}_{t,t+5}$) can be expressed as:

$$MissingBirths^{females}_{t,t+5} \equiv B_{t-5,t} \times [\frac{1}{1+SRB_{t-5,t}} - \frac{1}{1+SRB_{1970,1975}}] \qquad (6.3)$$

where $B_{t-5,t}$ refers to the births and the SRB is the sex ratio at birth.

Postnatal: Excess Female Child Mortality

For changes in the mortality component, quantifying 'excess' female mortality requires a counterfactual, or a model-generated estimate of what mortality would have been in the absence of gender discrimination. This standard, moreover, needs to account for the fact that the sex ratio of mortality changes with mortality decline. Assuming no sex-differential allocation of food and medical care, boys and girls have different probabilities of death due to a number of biological factors (Sawyer, 2012). Equity in survival chances during infancy and childhood does not entail a sex ratio of mortality of 1.

In the first year of life, newborn girls have a biological advantage over boys due to their lesser vulnerability to perinatal conditions, congenital abnormalities and certain infectious diseases such as intestinal infections and lower respiratory infections (Drevenstedt et al., 2008). The same biological advantages for girls with respect to infectious diseases do not transfer to later infancy or early childhood years. Consequently, the sex ratio of mortality in the first year of life is expected to be higher (indicative of higher male mortality compared to female mortality) than in in early childhood. Infections, in general, are more sex neutral in their mortality risks than congenital conditions. Since infections are more common in high mortality settings, the sex ratio of mortality in infancy and childhood tends to rise with declining mortality, as congenital conditions acquire greater importance as causes of deaths. In recent years, in high-income low-mortality settings, the sex ratio of infant mortality has started to fall again indicating improvements in the relative survival of male infants (Sawyer, 2012).

Previous attempts to quantify excess female infant and child mortality, most notably Hill and Upchurch (1995), used lifetables from historical data from European populations to generate an expected sex ratio of mortality at a given level of mortality. Hill and Upchurch (1995) modelled the sex ratio of infant and child mortality as a function of male under-5 mortality using a flexible, locally

weighted least squares regression model (Hill and Upchurch, 1995). This assumed that historical populations did not show significant sex discrimination in the allocation of food and resources. Sawyer (2012) found that while the direction of change observed in historical populations, with increasing sex ratios of infant and child mortality accompanying declines in overall mortality, have also been observed in the contemporary developing world, the extent of female advantage at a given level of mortality is lower in the developing world than in historical data. This result holds even when India and China, countries where excess female child mortality has been extensively documented in the demographic literature, are excluded.

The appropriateness of historical European populations to construct a standard of expected sex ratios of mortality for the contemporary developing world, given the vastly different environmental and cause of death environments between the two, has been further questioned in recent studies (Bongaarts and Guilmoto, 2015; Alkema et al., 2014). These studies pooled data from a wider set of contemporary populations reflecting different mortality environments to derive estimates of excess mortality. Similarly to Hill and Upchurch, Alkema et al. (2014) modelled sex ratios of infant and child mortality as a function of male under-five mortality, and separately estimated country-specific deviations from this global relationship with a Bayesian hierarchical time-series model. They used mortality estimates from the UN Inter-agency Group on Mortality Estimation (IGME) (Hill et al., 2012). The UN WPP 2015 revision uses the same analytical approach as the UN IGME to estimate under-five mortality (United Nations, 2015b). Pooling UN WPP (2012) data to form a reference group of 93 countries, Bongaarts and Guilmoto (2015) predicted logged sex ratios of mortality as a linear function of life expectancy. Their reference group comprised 93 countries excluding countries with populations of size less than 5 million, select Eastern European countries

and those where prenatal sex selection or excess female mortality have previously been documented.

In what follows, I draw on these different approaches. Following Alkema et al. (2014) and Hill and Upchurch (1995), I estimate a flexible locally weighted least squares regression model with the sex ratio of mortality as the outcome variable and probability of dying before the age of 5 for males (${}_5q_0^m$) as the predictor. This model is separately estimated for sex ratios of the infant probability of dying before age 1 ($\frac{{}_1q_0^m}{{}_1q_0^f}$), the probability of dying between ages 1 and 5 ($\frac{{}_4q_1^m}{{}_4q_1^f}$), and the probability of dying between ages 5 and 10 ($\frac{{}_4q_5^m}{{}_4q_5^f}$) using UN WPP (2015) data for the same 93 countries used by Bongaarts and Guilmoto. The model generates predicted sex ratios of mortality at a given level of male under-five mortality. From these estimates of the sex ratio of mortality, estimates of expected female $\widehat{{}_1q_0^f}$, $\widehat{{}_4q_1^f}$, and $\widehat{{}_4q_5^f}$ are derived, and corresponding person-years lived by the cohort between ages x and x+n can be computed (Preston et al., 2000). The person-years derived from the model-predicted $\widehat{{}_1q_0^f}$, $\widehat{{}_4q_1^f}$, and $\widehat{{}_4q_5^f}$ is the expected mortality component – ${}_5\widehat{L}_5^{f,t,t+5}$.

Re-applying eq. (6.2), the excess female deaths underlying the child sex ratio $CSR_{t,t+5}^{5-10}$ for period [t, t+5) can be expressed as:

$$ExcessDeaths_{t,t+5}^{f} = B_{t-5,t}^{f} \times [{}_5\widehat{L}_5^{f,t,t+5} -{}_5 L_5^{f,t,t+5}] \tag{6.4}$$

As existing literature on excess female mortality reports measures of mortality in terms of risk or probability of dying (qx) rather than person-years lived (Lx), in addition to the measure of excess female deaths from eq. 6.4, I will also follow the convention of reporting qx. Moreover, as most excess female mortality is concentrated in ages under five, I will report on under-five mortality in terms of the probability of dying under age 5 for females ${}_5q_0^f$, which is composed of two components – the probability of dying between age 0 and 1 or infant mortality

$(\widehat{{}_1q_0^f})$ and the probability of dying between ages 1 and 5 years $(\widehat{{}_4q_1^f})$ and can be expressed as $\widehat{{}_5q_0^f} = \widehat{{}_1q_0^f} + \widehat{{}_4q_1^f}(1 - \widehat{{}_1q_0^f})$ (Preston et al., 2000).

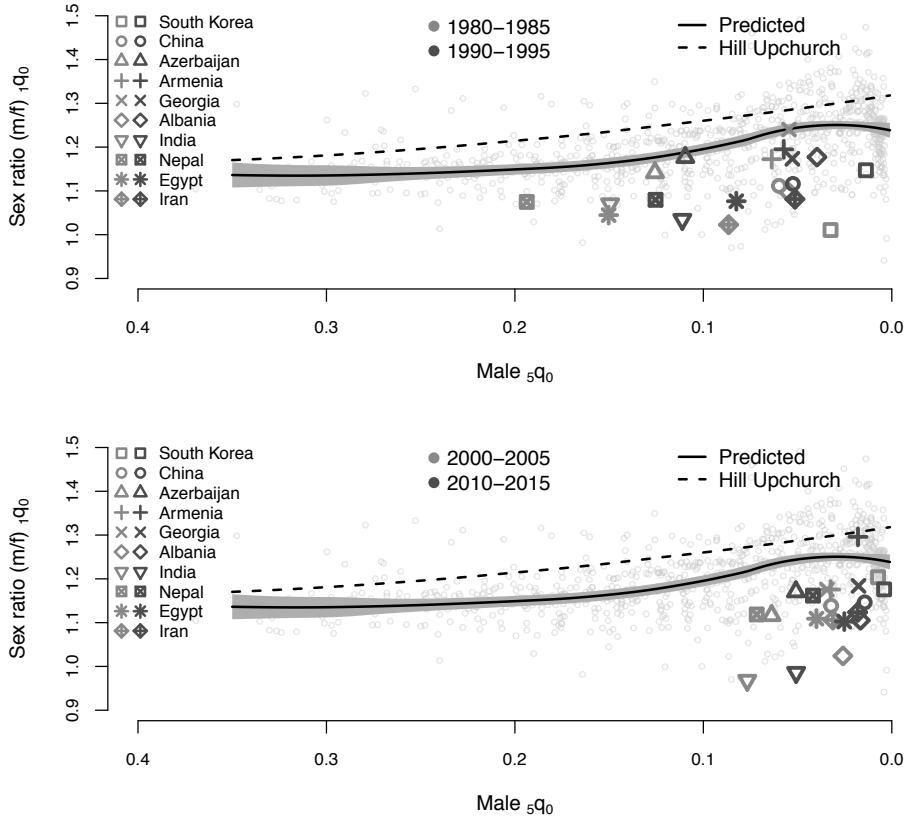


Figure 6.3: Model-predicted values of the sex ratio of infant mortality $({}_1q_0)$ as a function of male under-five $({}_5q_0^m)$ mortality. 99% confidence interval bands are shown in grey. Dashed line shows model-predicted values of sex ratios of $({}_1q_0)$ applying the Hill-Upchurch standard. Selected outliers ($p < 0.01$) indicating excess female infant mortality levels than expected for 1980-85 and 1990-95 are highlighted in the upper panel and 2000-05 and 2010-15 in the lower panel.

Predicted estimates of $\widehat{{}_5q_0^f}$ can be compared with lifetable estimates of the same for a given period to assess the extent of excess mortality in two measures: 1) *relative* excess female mortality: the ratio of lifetable mortality estimates to model-predicted, expected values of mortality (i.e $\frac{\widehat{{}_5q_0^f}}{{}_5q_0^f}$); 2) *absolute* excess female mortality: difference between lifetable estimates of mortality and expected mortality (i.e ${}_5q_0^f - \widehat{{}_5q_0^f}$). Both measure of relative and absolute excess female mortality are helpful in determining excess mortality at different levels of mor-

tality, especially as at low levels of overall mortality due to small death counts, sex ratios of infant and child mortality can fluctuate significantly over periods. Moreover, with declining mortality, absolute excess mortality might decline even if relative excess mortality remained stable or even increased. I rely on both measures to determine whether a country in a particular period shows excess female under-five mortality: it must indicate relative excess mortality levels greater than 1, and absolute excess mortality of at least 0.001 (1 excess death per 1000).

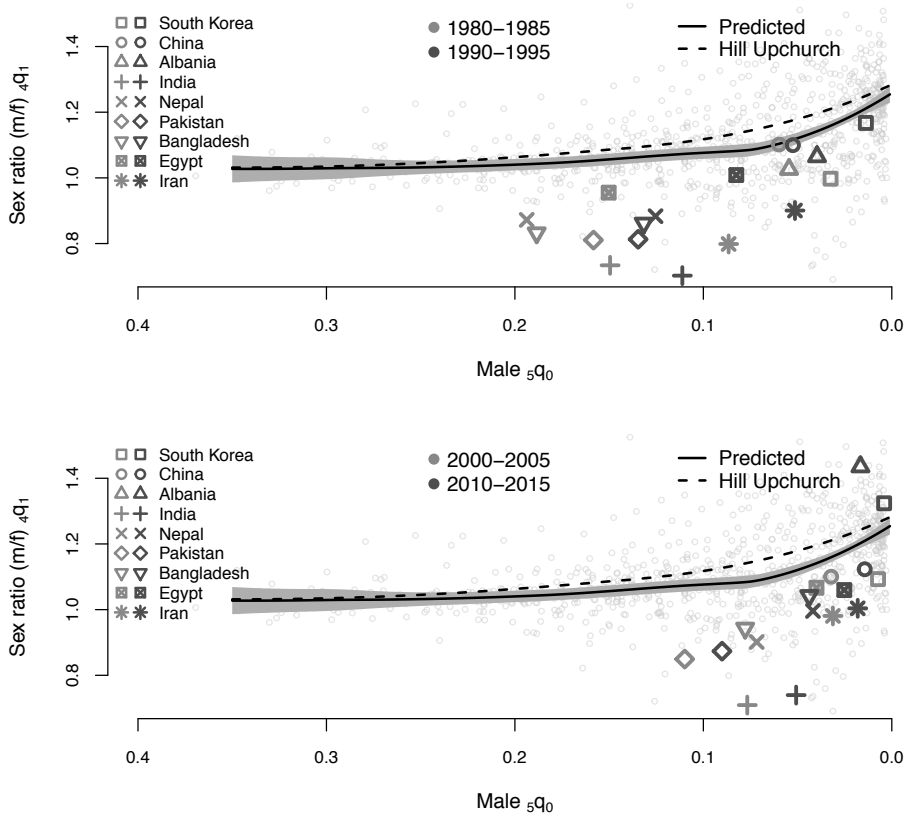


Figure 6.4: Model-predicted values of the sex ratio of child mortality ($_4q_1$) as a function of male under-five ($_5q_0^m$) mortality. 99% confidence interval bands are shown in grey. Dashed line shows model-predicted values of sex ratios of ($_4q_1$) applying the Hill-Upchurch standard. Selected outliers ($p < 0.01$) indicating excess female child mortality levels than expected for 1980-85 and 1990-95 are highlighted in the upper panel and 2000-05 and 2010-15 in the lower panel.

Figure 6.3 shows the model-predicted levels (black solid line) of female infant mortality ($_1q_0^f$), and Figure 6.4 shows the same for child ($_4q_1^f$) mortality levels. The corresponding predicted ratios of mortality from the Hill-Upchurch standard

are also depicted with the black dashed line. The figures highlight several countries – including both where prenatal sex selection is indicated in their SRBs (e.g South Korea, China, India) and others where it is not (e.g Iran, Egypt) – where excess female mortality at infant and child ages was observed in 1980-1985 and 1990-1995 in the top panel and outliers for 2000-2005 and 2010-2015 in the bottom panel. Statistically significant outlier countries ($p < 0.01$) where excess mortality was present throughout the study period are detailed in the appendix in Tables A.6.1 and A.6.2. In Fig. 6.3, the country point for South Korea exemplifies a context where excess infant mortality was observed for girls in 1980-85, which largely disappeared by 1990-95, as the country point moves from being well below the predicted line (in the direction of higher lifetable estimates of female ${}_1q_0^f$ than expected $\widehat{{}_1q_0^f}$) to being much closer to the predicted line by 1990-95. India, on the other hand, exemplifies a country that remains well below the line of expected levels of female mortality at both infant and child ages, even as mortality levels fall.

6.4 Results

6.4.1 Changes in Child Sex Ratios

CSRs were largely stable for the vast majority of countries across consecutive decades between 1980-85 to 2010-15. Fig. 6.5 plots the ratio of change across consecutive decades in CSRs between 1980-85 to 1990-95, 1990-95 to 2000-05, and 2000-05 to 2010-15. The figure identifies country outliers both on the right-tail, indicative of CSR change in the direction of increases in masculinity, and on the left-tail indicative of increases in femininity. Proximity between the two points along the horizontal-axis indicates geographical proximity between any two country-points.

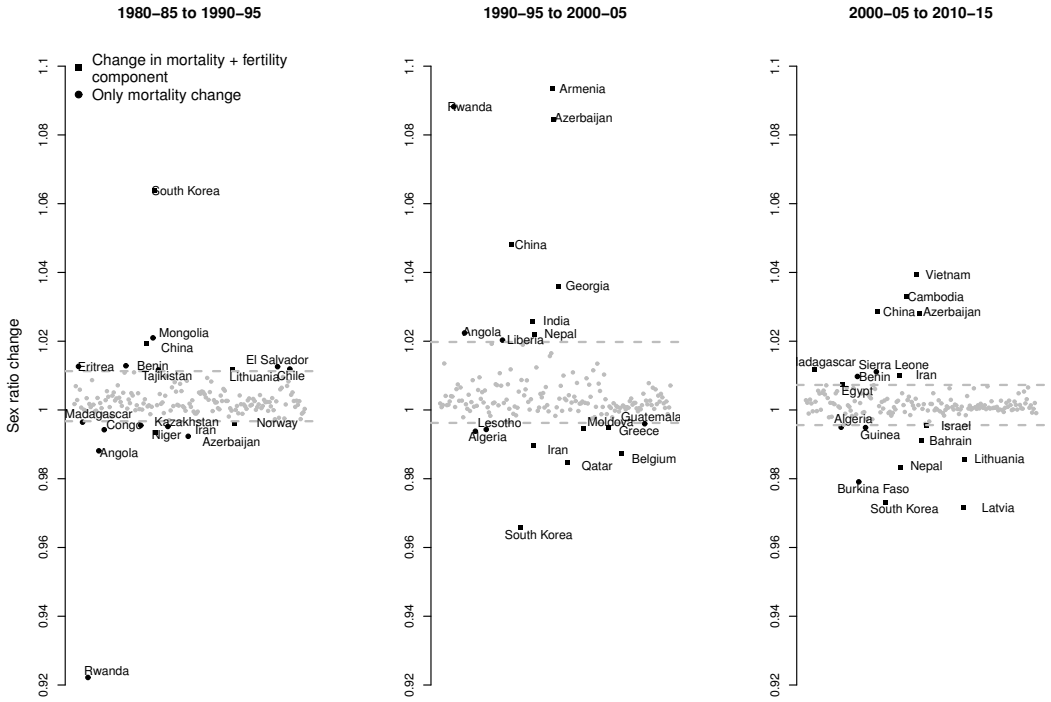


Figure 6.5: Changes in lifetable child sex ratios across consecutive decades – 1980-85 to 1990-95, 1990-95 to 2000-05, 2000-05 to 2010-15 – highlighting outlier countries experiencing the largest changes. The grey dotted lines identify the 90% range for the empirical distribution of the within-country changes observed between two consecutive periods.

The largest outliers were concentrated in the direction of increases in masculinity of CSRs. With the exception of Rwanda, countries experiencing the greatest magnitudes of change in their CSRs witnessed change in both the mortality and fertility components of their CSRs (denoted by a square in Fig. 6.5). Since the focus of this paper is to study the dynamics in both fertility and mortality components in CSRs, in what follows I will restrict my analysis to outliers where both components changed. There is a strong correspondence between countries that experienced the largest sex ratio changes and those with outlying sex ratio levels in each period. Details of outlying countries in terms of CSR levels are available in the appendix..

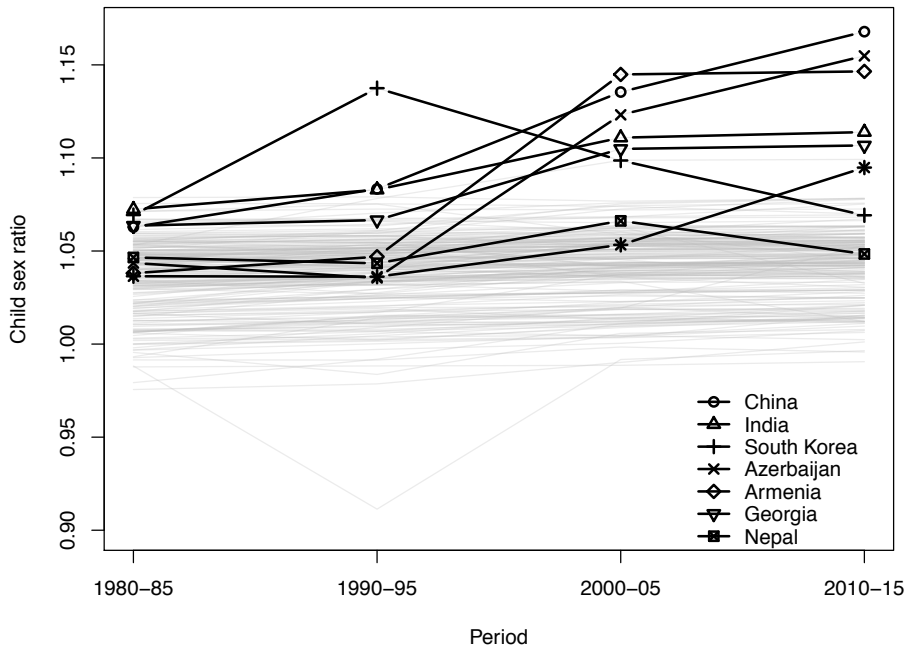


Figure 6.6: Lifetable child sex ratios, 1980-85 to 2010-15, highlighting countries with outlying trajectories witnessing significant increases in masculinity in their child sex ratios. Child sex ratio trajectories for all 171 countries between 1980-85 and 2010-15 are shown in grey in the background.

Fig. 6.6 highlights CSR trajectories of countries experiencing the largest increases in masculinity in Fig. 6.5 where change occurred both in their fertility and mortality components. The countries experiencing these outlying trajectories were in South (India, Nepal), East Asia (China, South Korea, Vietnam), the Caucasus (Georgia, Armenia, Azerbaijan).

6.4.2 East Asia

How much of the change in CSR trajectories was attributable to fertility and mortality dynamics? Fig. 6.7 highlights the ratio of change in the fertility component (indicated on the x-axis) and the mortality component (indicated on the y-axis) across consecutive decades – from 1980–1985 to 1990–95, 1990-95 and 2000–05 to 2010–15 for China, South Korea and Vietnam. The ratio of change is depicted here. Thus, for the fertility component underlying CSRs between 1980–85 and

1990–95 this is $\frac{SRB_{1985,1990}}{SRB_{1975,1980}}$. Values greater than 1 indicate that the ratio changed in the direction of increases in the proportion of male births across the two periods. Similarly, the ratio of change in the mortality component can be expressed as $\frac{\frac{{}_5L_5^{m,1990,1995}}{{}_5L_5^{f,1990,1995}}}{\frac{{}_5L_5^{m,1980,1985}}{{}_5L_5^{f,1980,1985}}}$. A ratio greater than 1 indicates that that boys made faster improvements than girls in survivorship across the two periods and ratios less than 1 indicate girls made faster improvements in survivorship relative to boys. The substitution hypothesis would imply that increases in the fertility component in the direction of increased masculinity of the birth cohorts (greater than 1) are offset by faster improvements in girls' survivorship relative to boys (less than 1) if the country had excess levels of female under-five mortality in the preceding period. In Fig. 6.7 black points that lie in the lower right rectangle would meet these criteria. For each country, measures of relative excess ${}_5q_0^f$, absolute excess ${}_5q_0^f$, absolute number missing female births (see eq. (6.3)), excess female deaths (see eq. (6.4)) underlying the CSR are highlighted in Table 6.1.

For all three countries the mortality component changed much less than the fertility component in explaining the dynamics of the CSRs across the three panels in Fig. 6.7. The greater contribution of the fertility component in absolute terms as the number of missing births as compared with excess female deaths is highlighted in Table 6.1.

Of the three East Asian contexts, South Korea shows the clearest evidence suggestive of substitution between 1980–85 to 1990–95. Although levels of excess female mortality in South Korea were relatively low compared with China (see Table 6.1) or India (see Table 6.2) already in 1980–85, slight changes in the mortality component between 1980–85 and 1990–95 were indicative of reductions in excess female child mortality, with excess mortality disappearing by the early 2000s. As Table 6.1 highlights, relative excess female mortality levels fell from around 20% excess mortality to around 5% excess mortality.

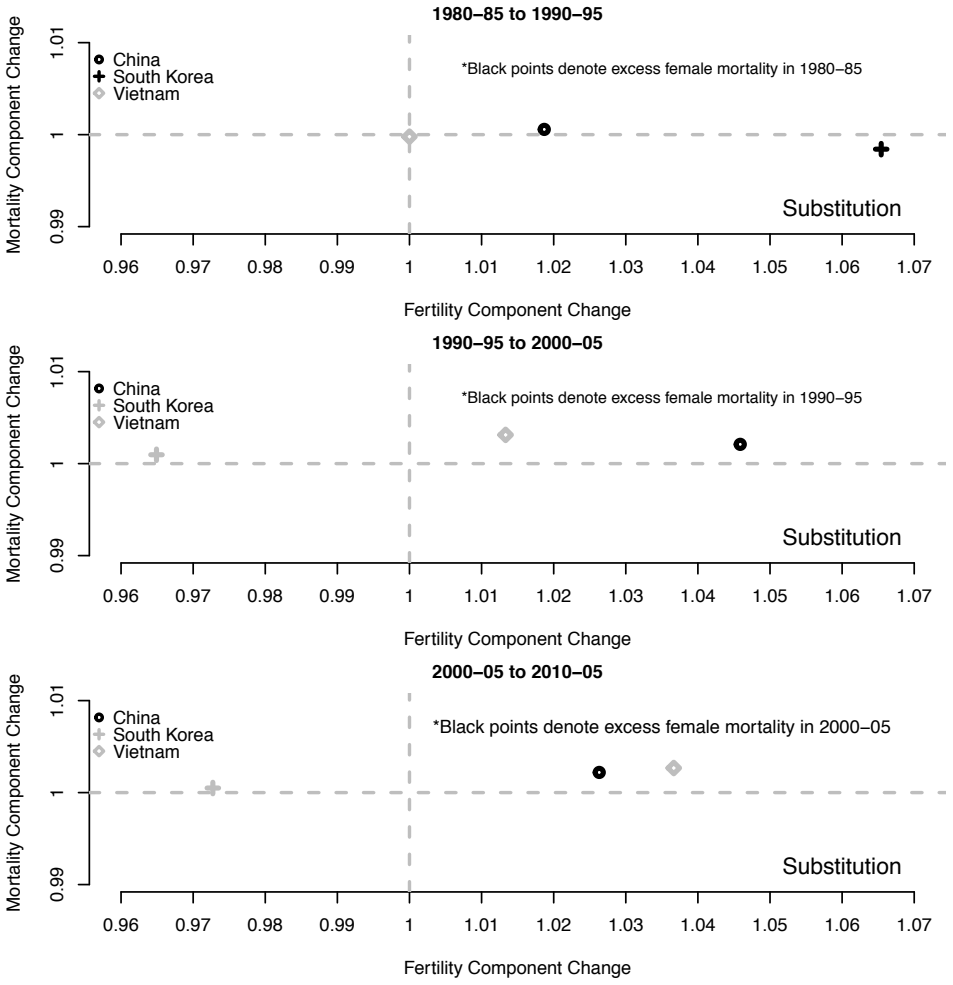


Figure 6.7: Changes in fertility and mortality components underlying child sex ratios in China, South Korea and Vietnam, across consecutive decades – 1980-1985 to 1990-95, 1990-95 to 2000-05 and 2000-05 to 2010-2015.

Between 1990–95 and 2000–05, the fertility component in South Korea showed significant reductions in masculinity, indicating the decline of prenatal sex selection. China saw increases in its fertility component later than in South Korea, with the most noticeable change in the period after the 1990s. Unlike in South Korea, changes in the mortality component over the period when prenatal sex selection increased, did not show a decline but a stabilisation in the levels of relative excess female mortality. Despite stabilisation in relative excess mortality however, absolute numbers of excess female deaths declined in China between 2000-05

Table 6.1: Missing female births (in thousands), excess female deaths (in thousands) and absolute excess under-five mortality (per 1000 births) underlying child sex ratios for China, South Korea and Vietnam, 1980-85, 1990-95, 2000-05, 2010-15. Note: Relative excess mortality refers to the ratio of lifetable estimates to model-predicted female ${}_5q_0^f$. Absolute excess mortality refers to the difference between lifetable estimates and model predicted ${}_5q_0^f$.

Country	**Indicator**	**1980-85**	**1990-95**	**2000-05**	**2010-15**
China	Excess female deaths	240.7	271.7	98.9	44.7
China	Missing female births	0	642.8	1311.2	1790.2
China	Relative excess ${}_5q_0^f$	1.09	1.09	1.09	1.09
China	Absolute excess ${}_5q_0^f$	4	4	2	1
South Korea	Excess female deaths	12.5	1.2	0.5	0.1
South Korea	Missing female births	0	51.1	21.3	0
South Korea	Relative excess ${}_5q_0^f$	1.22	1.07	1.05	1.03
South Korea	Absolute excess ${}_5q_0^f$	6	1	0	0
Vietnam	Excess female deaths	-4.2	-14.9	-9.5	-6.3
Vietnam	Missing female births	0	0	24.8	91.7
Vietnam	Relative excess ${}_5q_0^f$	1.00	0.95	0.94	0.94
Vietnam	Absolute excess ${}_5q_0^f$	0	-2	-2	-1

and 2010-15, after showing a slight increase between 1980–85 and 1990–95 (see Table 6.1).

For China, a number of commentators link fertility restrictions in the form of the one-child policy that were put in place in the 1979 with an intensification of prenatal sex selection (Guilmoto, 2009). However, the policies were implemented well before the widespread availability of prenatal sex determination technologies, which were likely not a significant factor underlying China's SRB increases before the 1990s (Goodkind, 2015). For those constrained by the fertility restrictions in the 1980s, son preference likely manifested itself either in the systematic underreporting of daughters (Goodkind, 2011; Merli and Raftery, 2000) or the potential intensification of postnatal excess mortality at low birth parities. The mortality effects of the fertility restrictions are suggested by the fact that in the period between 1980-85 and 1990-95, when the diffusion of prenatal sex determination technologies was likely low, both relative and absolute excess female mortality remained high as shown in Table 6.1. In a context of strong son preference, fertil-

ity restrictions, and variations in regional development that would likely trigger a more gradual and stratified diffusion of prenatal sex determination technology, these trends suggest that the uptake of prenatal sex selection especially among groups where excess female mortality may have been limited.

Vietnam saw significant increases in prenatal sex selection particularly in the period between 2000-05 and 2010-15 when the fertility component increased by 4% from 1.07 to 1.11. Unlike South Korea and China, Vietnam did not indicate excess female child mortality either before or during the period when uptake of prenatal sex selection was visible. Interestingly, Table 6.1 shows that Vietnam indicated slight levels of excess male mortality and had fewer female deaths than predicted for all four periods. Vietnam's neighbour, Cambodia, identified as an outlier in terms of sex ratio change in Fig. 6.5, showed a slight elevation from 1.04 to 1.06 in its fertility component. Similarly to Vietnam, this occurred in the absence of any excess female mortality either preceding or during the period that witnessed the change in the fertility component. In the 1980s and 1990s, the SRB in Cambodia was in the range of 1.03 and 1.04, which are lower than SRB values for Vietnam (1.05). It is unclear whether prenatal sex selection underlies these changes in the SRB in Cambodia.

6.4.3 South Asia

In South Asia, India, Pakistan and Nepal all showed some evidence for substitution in the 2000s. Girls experienced faster improvements in mortality reduction than boys, as indicated by a change in mortality components under 1 in Fig. 6.8 in all three countries after 1990–95 that accompanied increases in masculinity in their fertility components in the 1990–95 to 2000–05 period. Given the high levels of excess female mortality present in South Asia as highlighted in Table 6.2, faster improvements only gradually reduced high prevailing levels of excess fe-

male mortality in the 2000s, with Nepal showing the the biggest reductions in the region.

Table 6.2: Missing female births (in thousands), excess female deaths (in thousands), relative excess under-five mortality, and absolute excess under-five mortality (per 1000 births) underlying child sex ratios for India, Pakistan, and Nepal, 1980-85, 1990-95, 2000-05, 2010-15.

Country	**Indicator**	**1980-85**	**1990-95**	**2000-05**	**2010-15**
India	Excess female deaths	1835.2	1882.7	1573.1	920.8
India	Missing female births	0	319.5	1253.8	1536.3
India	Relative excess ${}_5q_0^f$	1.19	1.25	1.32	1.31
India	Absolute excess ${}_5q_0^f$	25	24	21	13
Nepal	Excess female deaths	35.8	28.2	15.5	5.1
Nepal	Missing female births	0	0	23.8	7.1
Nepal	Relative excess ${}_5q_0^f$	1.11	1.12	1.12	1.09
Nepal	Absolute excess ${}_5q_0^f$	19	13	7	3
Pakistan	Excess female deaths	123.1	145.3	111.8	89.4
Pakistan	Missing female births	0	0	78.2	119.3
Pakistan	Relative excess ${}_5q_0^f$	1.10	1.10	1.09	1.08
Pakistan	Absolute excess ${}_5q_0^f$	14	12	9	6

Changes in the mortality components between 1980–85 and 1990–95 were indicative of either stability (Pakistan, India) or slight reductions (Nepal) in the levels of both relative and absolute excess female mortality. In both Pakistan and Nepal, little change in the fertility component was evident between 1980–85 and 1990–95. India showed the highest levels of under-five excess female mortality in the world. In 2010–15, 1.5 million missing female births comprised the population of 5-10 year olds compared with 920,000 excess female deaths. Numbers of excess female deaths accounted for a greater number of missing girls in India until 2000–05, after which missing female births contributed more than excess female deaths. The faster pace of mortality reduction for girls that accompanied the masculinity of its fertility component as shown in Fig. 6.8 was not sufficient to make India less of an outlier in terms of its levels of relative excess mortality levels. As highlighted in Table 6.2, although between 1990-95 and 2000-05, and more significantly between 2000-05 and 2010-15, absolute excess mortality levels

and absolute numbers of excess female deaths declined in India, relative excess female mortality levels were remarkably persistent.

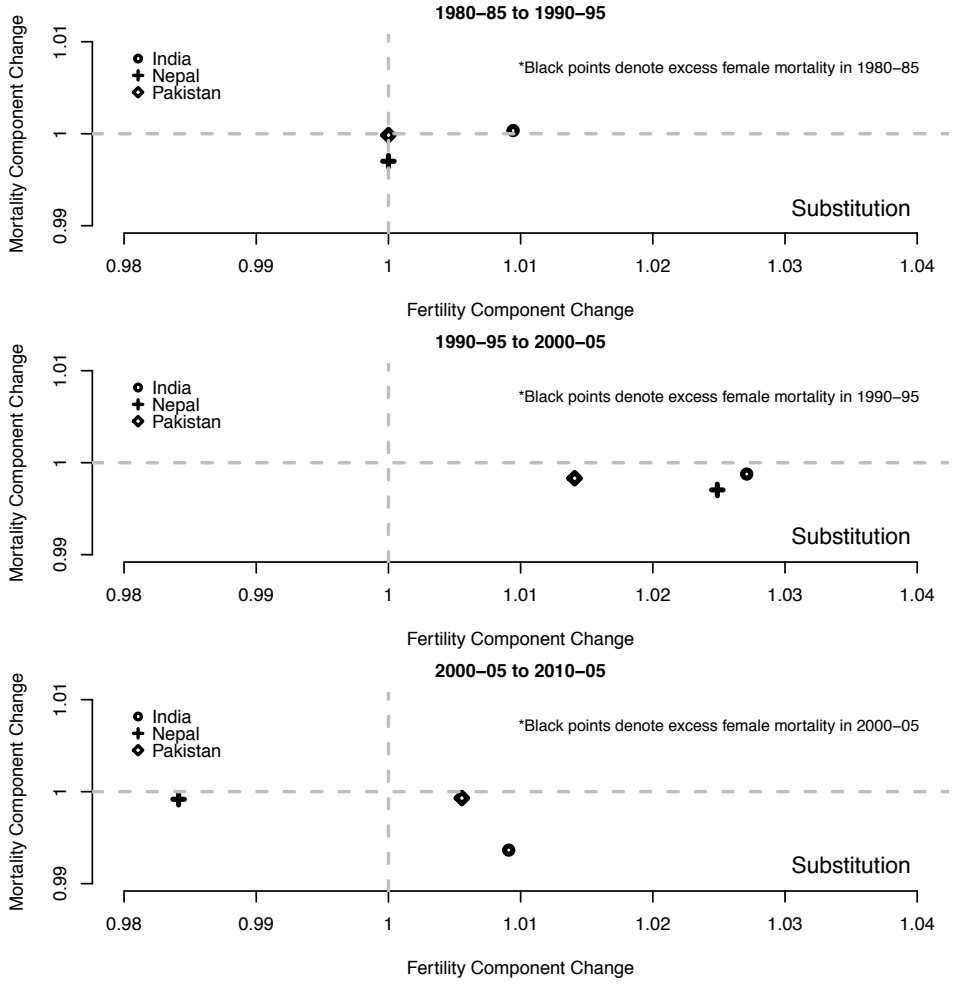


Figure 6.8: Changes in fertility and mortality components underlying child sex ratios in India, Pakistan and Nepal across consecutive decades – 1980-1985 to 1990-95, 1990-95 to 2000-05 and 2000-05 to 2010-2015.

As anticipated, in early- and mid-transition contexts with strong son preference, higher fertility and high prevailing levels of excess mortality such as South Asia, the contributions of excess female mortality to sex ratio distortions remained significant even as the fertility component became distorted. Reductions in excess mortality only appeared in the 2000s, coinciding with a slowdown in increases in the fertility component. This patterns suggests that prenatal sex selection may have become more widely practiced in the 2000s than in the initial stages of

the rise in SRBs when it was likely concentrated among pioneer groups such as the richer and better educated. India witnessed the most gradual reductions in excess female mortality in the region. It also witnessed the largest increases in the fertility component in South Asia, followed by Nepal and then Pakistan. In Nepal, changes in the fertility component appeared later than in India between 1990–95 and 2000–05, and SRB trajectories began to level-off already between 2000–05 and 2010–15. Abortion legalisation in 2002 in Nepal may have played an important role in the onset of prenatal sex selection in the early-2000s in the country unlike in the Indian context where abortion has been legal since the 1970s (Frost et al., 2013).

6.4.4 West Asia

Azerbaijan, Armenia and Georgia saw sharp rises in their SRBs indicative of the onset of prenatal sex selection in the 1990s. No other parts of the former Soviet Republics spanning Southern Europe to Central Asia witnessed a similar rise in their SRBs following independence from the Soviet Union, with the exception of Albania. In contrast to East and South Asian contexts, the South Caucasus countries saw a simultaneous emergence of excess female mortality in the 1990s (Georgia, see 1990–95 to 2000–05 panel in Fig. 6.9) or early 2000s (Azerbaijan and Armenia, see 2000–05 to 2010–05 panel in Fig. 6.9) coinciding with sharp increases in SRB distortions. Azerbaijan indicated higher than expected levels of female ${}_5q_0^f$ in the 1980–85 period initially, which had normalised by 1990–95. Between 1990–95 and 2000–05, the mortality component saw a nearly 2% increase in masculinity – resulting in the re-emergence of excess female mortality coinciding with the period its SRBs witnessed distortions. Period conditions that likely resulted in the strengthening of the incentives to bear a son following the collapse of the Soviet Union in the 1990s also appear to have triggered postnatal excess female mortality in the region.

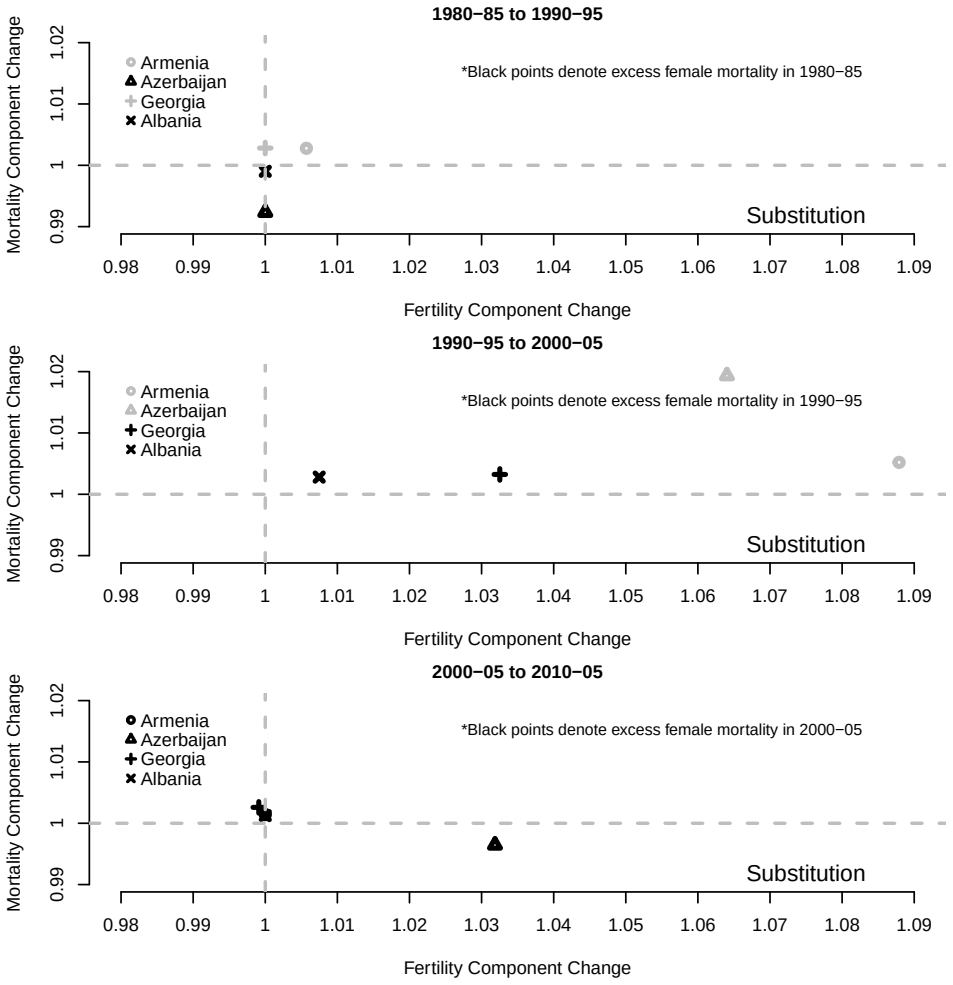


Figure 6.9: Changes in fertility and mortality components underlying child sex ratios in Armenia, Azerbaijan, Georgia and Albania across consecutive decades, 1980-85 to 1990-95, 1990-95 to 2000-05, and 2000-05 to 2010-15.

Notably, the marker for Albania in Fig. 6.9 remains black in all three panels indicating that the country showed excess female mortality prior to the 1990s and throughout the period under consideration. As shown in Table 6.3, the levels of excess female mortality in the Caucasus and Albania were similar to estimates from South Korea, and considerably lower than those in South Asia and China. Missing female births accounted for a greater fraction of the distortion in child sex ratios than excess female deaths for the four countries. Fig. 6.9 highlights that between 1990–95 and 2000–05 the fertility component increased in all four countries, with the steepest increases in Armenia, followed by Azerbaijan, Georgia

and Albania. Although UN SRB figures for Azerbaijan, Armenia and Georgia correspond with the SRB data from their statistical offices, the UN figures for SRBs are likely underestimating SRB increases for Albania. According to UN figures, SRBs increased from 1.07 to 1.08 between 1990-95 and 2000-05 in Albania. Birth registration data for 2006 showed an SRB of 116 (Guilmoto, 2009), whereas for the period between 2008-11 it was estimated to be 111.7 (UNFPA, 2012).

Table 6.3: Missing female births (in thousands), excess female deaths (in thousands) and absolute excess under-five mortality (per 1000 births) underlying child sex ratios for Armenia, Azerbaijan, Georgia and Albania, 1980-85, 1990-95, 2000-05, 2010-15.

Country	**Indicator**	**1980-85**	**1990-95**	**2000-05**	**2010-15**
Armenia	Excess female deaths	-0.2	0.1	0.1	0
Armenia	Missing female births	-0.4	0.1	4.5	4.5
Armenia	Relative excess ${}_5q_0^f$	0.99	1.01	1.05	0.98
Armenia	Absolute excess ${}_5q_0^f$	-1	0	1	0
Azerbaijan	Excess female deaths	0.3	-3.6	2.1	0.2
Azerbaijan	Missing female births	0	0	11.6	21.7
Azerbaijan	Relative excess ${}_5q_0^f$	1.03	0.95	1.10	1.02
Azerbaijan	Absolute excess ${}_5q_0^f$	-3	-5	6	1
Georgia	Excess female deaths	-0.1	0.4	0.2	0.1
Georgia	Missing female births	0	0	2.5	2.4
Georgia	Relative excess ${}_5q_0^f$	1.00	1.05	1.05	1.05
Georgia	Absolute excess ${}_5q_0^f$	0	2	2	1
Albania	Excess female deaths	0.9	0.4	0.3	0.1
Albania	Missing female births	0	0	0.5	0.3
Albania	Relative excess ${}_5q_0^f$	1.12	1.06	1.09	1.10
Albania	Absolute excess ${}_5q_0^f$	5	2	2	1

Changes in the mortality component remained stable above 1 in Fig. 6.9 between 1990–95 and 2000–05 for Georgia and Albania, indicating that slight excess levels of female mortality persisted as their fertility component increased and subsequently levelled off between 2000–05 and 2010–15. Azerbaijan and Armenia witnessed faster reductions in mortality for girls between 2000–05 and 2010–15 as changes in the fertility component levelled off over this period. Azerbaijan, with higher fertility and mortality levels, is at an earlier stage of the demographic transition than the other Caucasus countries and saw a greater contribution of

excess mortality to its sex ratio distortions. In contrast, as highlighted in Table 6.3, Armenia showed only slight excess female mortality levels in 2000–05 that disappeared by 2010–15. Although this study finds slight excess mortality in Georgia in the 1990s and 2000s and in Albania from 1980–85 to 2010–15, Alkema et al. (2014) did not find Georgia and Albania to have outlying sex ratios of mortality in their analysis of of excess female under-five mortality for 1990 and 2012, but found Azerbaijan to be an outlier in both 1990 and 2012, although with reductions in excess female mortality across the two periods.

6.5 Conclusions

By 2010–15, in all countries where SRB distortions were noted, missing female births resulting from prenatal sex selection contributed significantly more than excess female deaths to increases in masculinity of child sex ratios. This finding at the country-level concurs with aggregate, global trends in prenatal and postnatal contributions to missing women reported in Bongaarts and Guilmoto (2015). From the 1990s onward, this steady increase in the contribution of missing female births within countries was accompanied by reductions in absolute numbers of excess female deaths at infant and childhood ages. Nevertheless, changes in relative excess female mortality for cohorts experiencing rises in prenatal sex selection were more ambiguous.

In South Korea, swift substitution, implied by the reductions in both relative and absolute excess female mortality for (synthetic) cohorts experiencing increases in SRBs, was found. In South Asia, a less steep rise in SRBs was accompanied by initial stability followed by gradual reductions in prevailing high levels of absolute and relative excess female mortality in the 2000s. High levels (30%) of relative excess female mortality in India persisted until 2010–15. Indeed, although levels of both absolute and relative excess female mortality were much

lower in China, like India little reductions in relative excess mortality accompanied SRB rise in China. It is plausible that widespread son preference combined limited overlap between populations that practice prenatal and postnatal forms of sex selection might explain the persistence of relative excess female mortality in both settings. The mortality components of the Caucasus countries of Armenia, Azerbaijan and Georgia showed the onset of excess female mortality in the 1990s and early 2000s coinciding the the emergence of prenatal sex selection in these populations. In contrast in Albania, slight excess female mortality was noted throughout the period from 1980–85 to 2010–15. In these populations at a later stage of the demographic transition with presumably weaker son preference than South Asia, a swift uptake of prenatal sex selection accompanied by reductions in excess female mortality would be expected to underpin changes in child sex ratios. This pattern was indicated by Azerbaijan and Armenia in the 2000s. Albania and Georgia saw a persistence of slight relative excess mortality levels even as the SRBs became distorted, although reductions in absolute excess mortality were noted in these countries as well.

With the exception of Vietnam, this study shows postnatal excess female mortality has been a precursor to, or coincided with, the emergence of prenatal sex selection. It is important to note though that a number of countries had outlying sex ratios of mortality indicative of postnatal excess mortality without clear evidence for prenatal sex selection. This study has largely focused on examining mortality dynamics in countries that experienced prenatal sex selection. A few countries showing excess ${}_1q_0^f$ and ${}_4q_1^f$ are highlighted in Fig. 6.3 and Fig. 6.4 respectively, and all outliers for the period between 1980–2015 listed in the appendix. These countries exist in geographical clusters, with significant concentrations of excess female child mortality in the Middle East and North Africa (Iran, Egypt, Jordan, Bahrain), as well as others in sub-Saharan Africa (such as Mali, Niger, Nigeria). Bangladesh, too, showed high levels of excess female child mortality.

Moreover, in Iran, Egypt and Bangladesh, among others, reductions in excess female mortality were observed since the 1990s without any corresponding increase in SRBs.

Why have SRB distortions emerged in some but not all contexts where postnatal excess female mortality was present? Bongaarts has speculated whether there may be pent-up demand for sex-selective abortion in parts of Africa, where son preference is present and excess female mortality is indicated, that is currently constrained due to limited access to ultrasound and abortion (Bongaarts, 2013). Limited access to abortion, or its limited uptake due to religious grounds, may also be responsible for why SRB distortions were not observed in Iran or Egypt (Hessini, 2007). For the Bangladeshi context though, Kabeer et al. (2014) have claimed that limited access to technology, restricted abortion access, or the presence of Islamic norms with weaker son preference unlike its Hindu neighbours, India and Nepal, do not provide sufficient explanations for why prenatal sex selection did not spread (Kabeer et al., 2014). They attribute the significant role played by civil society in shifting norms surrounding sex preferences in explaining the divergent trajectories observed in Bangladesh compared with its South Asian neighbours.

As the discussion above clarifies, significant postnatal excess female mortality can exist and decline without the uptake of prenatal sex selection. This highlights the challenges of clarifying the causal contribution of the uptake of prenatal sex-selection as distinct from the weakening of son preference norms to the decline of excess female mortality with the empirical approach undertaken in this study. In contrast to micro-level studies that have attempted to estimate causal impacts but often relied on assumptions that are country-specific, the aggregate-level framework developed in this paper can be applied across countries to measure the contributions and dynamics of prenatal and postnatal strategies of sex selection on sex ratios. This work draws on approaches to measuring excess mortality

presented in Alkema et al. (2014), whilst extending their work by jointly examining mortality and fertility dynamics. In contrast to more global trends in missing women at all ages reported by Bongaarts and Guilmoto (2015), this work focuses on country-level trends, and presents both measures of relative and absolute excess under-five female mortality to better understand country-level magnitudes and trends in the prenatal and postnatal manifestations of son preference.

The findings presented here highlight a number of open questions and issues of policy relevance. In light of the finding that missing female births now contribute more than excess female deaths in all countries that have experienced the emergence of prenatal sex selection, investigating factors that lead to the slowdown in prenatal sex selection and its eventual turnaround, such as that witnessed in South Korean SRB trajectories, is especially significant. Furthermore, research that examines the processes that lead to the uptake of prenatal sex selection in some contexts but not others is needed. Although absolute numbers of excess female deaths have declined in recent decades across different countries with son preference, relative excess female mortality in infant and childhood ages persists, most notably in India and China. Understanding the contributing factors and pathways to reduce gender gaps in mortality remains an important area of research with significant policy implications. In addition to its empirical contributions, a contribution of this study has been to theorise the relationship between prenatal and postnatal strategies of sex selection and present a framework for thinking about this relationship at different stages of demographic modernisation. This remains an area for further theoretical development and empirical research.

Appendix

Appendix 6.A Data Quality

The setup presented in this study examines the fertility and mortality changes underpinning changes in child sex ratios. The setup does not account for sex-differential migration dynamics. This assumes that sex-differential migration at childhood ages is not a significant factor in determining the dynamics of CSRs, which is an assumption also made in previous research (Bongaarts and Guilmoto, 2015). Although migration dynamics can be included in eq. 6.2, data on international migration are not as widely available nor easily harmonised as mortality and fertility data (United Nations, 2002).

A number of limitations related to data quality pertaining to the United Nations World Population Prospects (UN WPP) estimates should be noted. Similarly to other work using UN data (Bongaarts and Guilmoto, 2015) this study does not make any corrections to the data to account for sources of bias such female underenumeration for correcting sex ratios at birth or sex-specific mortality measures. Each new edition of the UN WPP estimates is revised to account for newly-available data sources (United Nations, 2015b). SRB time-series have often been revised accordingly across different editions to account for factors such as under-enumeration (Attané and Guilmoto, 2007). For a number of African countries for which data sources such as censuses or death registration systems are very limited, lifetable estimates rely heavily on model life tables (United Na-

tions, 2015b). The estimates of excess female mortality, such as those reported in the appendix in Tables A.6.1 and A.6.2 may be an artefact of these models as a result. Data sources used to generate UN estimates vary by country, and range from vital registration, such as those in high-income countries, to census or birth history data from sources such as the Demographic and Health Surveys or Multiple Indicator Cluster Surveys. The quality of the estimates may consequently vary considerably across countries depending on sources used.

Appendix 6.B Outliers: Child Sex Ratio Levels



Figure A.6.1: Country outliers in child sex ratios levels for 1980–85 and 1990–95. The grey dashed lines identify the 90% range for the empirical distribution of the sex ratios computed for each period.

The main text of the chapter gives greater emphasis to changes in the components underlying sex ratio dynamics. Countries with outlying trajectories in terms of changes in their sex ratios across consecutive decades also feature prominently in Fig. A.6.1 and Fig. A.6.2, which highlight values above the 5th percentile and below the 95th percentile for each period.

In general, more masculine (higher) sex ratios are concentrated in countries of south (India, Pakistan), west (Azerbaijan, Armenia, Georgia), and east Asia (Singapore, Hong Kong, China, South Korea), as well as parts of southern Europe (Montenegro, Albania, Greece) whereas lower values are concentrated in countries of sub-Saharan Africa. The low CSRs in sub-Saharan Africa are largely explained

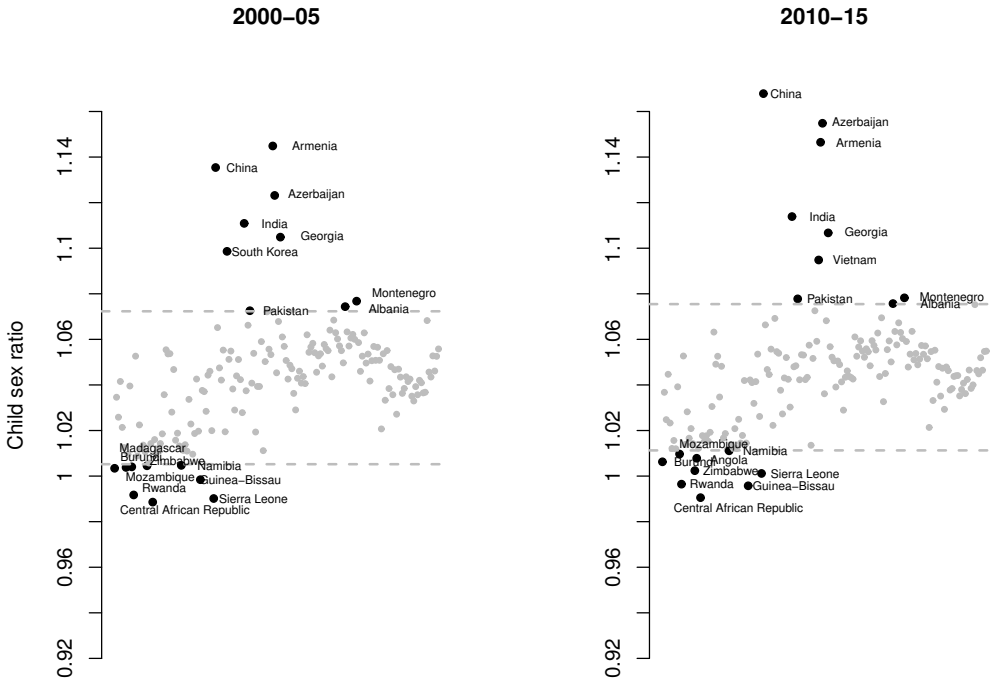


Figure A.6.2: Country outliers in child sex ratios levels for 2000–05 and 2010–15. The grey dashed lines identify the 90% range for the empirical distribution of the sex ratios computed for each period.

by low levels of SRBs (fertility component) (Garenne, 2002). The elevated SRBs in Singapore and Hong Kong have also been noted in the demographic literature as at least partly accounted for by prenatal sex selection. The extent of sex selection is thought to be less widespread than other Asian countries and instead concentrated to specific ethnic groups – e.g ethnic Indians in Singapore (Goodkind 1996, endnote 6) or mainland Chinese in Hong Kong who have used the region as an outlet for 'maternity migration' to circumvent one child policy restrictions (Basten and Verropoulou, 2013).

Appendix 6.C Tables

Country	Indicator	1980-85	1990-95	2000-05	2010-15
Afghanistan	Relative excess ${}_1q_0^f$	1.037	1.031	1.051	1.063
Afghanistan	Absolute excess ${}_1q_0^f$	5	3	4	4
Albania	Relative excess ${}_1q_0^f$	1.133	1.061	1.221	1.129
Albania	Absolute excess ${}_1q_0^f$	5	2	4	2
Azerbaijan	Relative excess ${}_1q_0^f$	1.031	1.01	1.105	1.063
Azerbaijan	Absolute excess ${}_1q_0^f$	2	1	5	2
Bahrain	Relative excess ${}_1q_0^f$	1.161	1.279	1.207	1.025
Bahrain	Absolute excess ${}_1q_0^f$	3	3	2	0
Bangladesh	Relative excess ${}_1q_0^f$	1.007	1.028	1.068	1.058
Bangladesh	Absolute excess ${}_1q_0^f$	1	2	3	2
Chad	Relative excess ${}_1q_0^f$	1.02	1.011	1.029	1.032
Chad	Absolute excess ${}_1q_0^f$	2	1	3	3
China	Relative excess ${}_1q_0^f$	1.113	1.114	1.098	1.088
China	Absolute excess ${}_1q_0^f$	4	4	2	1
Egypt	Relative excess ${}_1q_0^f$	1.114	1.125	1.126	1.134
Egypt	Absolute excess ${}_1q_0^f$	11	6	3	2
Ghana	Relative excess ${}_1q_0^f$	1.024	1.084	1.1	1.083
Ghana	Absolute excess ${}_1q_0^f$	2	5	5	4
India	Relative excess ${}_1q_0^f$	1.088	1.147	1.257	1.262
India	Absolute excess ${}_1q_0^f$	8	10	12	9
Iran	Relative excess ${}_1q_0^f$	1.181	1.15	1.131	1.111
Iran	Absolute excess ${}_1q_0^f$	11	5	3	1
Iraq	Relative excess ${}_1q_0^f$	1.084	1.084	1.08	1.024
Iraq	Absolute excess ${}_1q_0^f$	3	3	2	1
Jamaica	Relative excess ${}_1q_0^f$	1.13	1.085	1.097	1.09
Jamaica	Absolute excess ${}_1q_0^f$	3	2	2	1
Madagascar	Relative excess ${}_1q_0^f$	1.055	1.046	1.087	1.107
Madagascar	Absolute excess ${}_1q_0^f$	5	4	4	3
Malawi	Relative excess ${}_1q_0^f$	1.04	1.056	1.073	1.083
Malawi	Absolute excess ${}_1q_0^f$	6	7	7	4
Morocco	Relative excess ${}_1q_0^f$	1.045	1.042	1.065	1.041
Morocco	Absolute excess ${}_1q_0^f$	3	2	2	1
Nepal	Relative excess ${}_1q_0^f$	1.07	1.09	1.094	1.074
Nepal	Absolute excess ${}_1q_0^f$	8	7	4	2
Nigeria	Relative excess ${}_1q_0^f$	1.009	1.015	1.029	1.067
Nigeria	Absolute excess ${}_1q_0^f$	1	2	3	5
Oman	Relative excess ${}_1q_0^f$	1.113	1.137	1.121	1.161

Continued...

Country	**Indicator**	**1980-85**	**1990-95**	**2000-05**	**2010-15**
Oman	Absolute excess ${}_1q_0^f$	6	4	1	1
Pakistan	Relative excess ${}_1q_0^f$	1.043	1.046	1.049	1.049
Pakistan	Absolute excess ${}_1q_0^f$	5	4	4	3
Qatar	Relative excess ${}_1q_0^f$	1.11	1.147	1.185	1.173
Qatar	Absolute excess ${}_1q_0^f$	2	2	1	1
Saudi Arabia	Relative excess ${}_1q_0^f$	1.044	1.082	1.192	1.18
Saudi Arabia	Absolute excess ${}_1q_0^f$	2	2	3	2
Senegal	Relative excess ${}_1q_0^f$	1.017	1.029	1.039	1.026
Senegal	Absolute excess ${}_1q_0^f$	1	2	2	1
Sudan	Relative excess ${}_1q_0^f$	1.009	1.019	1.035	1.098
Sudan	Absolute excess ${}_1q_0^f$	1	1	2	5
Tunisia	Relative excess ${}_1q_0^f$	1.055	1.028	1.129	1.145
Tunisia	Absolute excess ${}_1q_0^f$	3	1	2	2
Yemen	Relative excess ${}_1q_0^f$	1.011	1.035	1.05	1.043
Yemen	Absolute excess ${}_1q_0^f$	1	3	3	2

Table A.6.1: Significant outlier countries that showed excess female infant mortality (${}_1q_0^f$) from 1980-85 to 2010-15. *Relative* excess female mortality refers to the ratio of lifetable estimated to model-predicted ${}_1q_0^f$. *Absolute* excess female mortality refers to the difference between lifetable estimates and model-predicted female ${}_1q_0^f$. This is expressed in terms of the deaths per 1000 births.

Country	**Indicator**	**1980-85**	**1990-95**	**2000-05**	**2010-15**
Afghanistan	Relative excess ${}_4q_1^f$	1.073	1.105	1.121	1.125
Afghanistan	Absolute excess ${}_4q_1^f$	7	6	5	3
Bangladesh	Relative excess ${}_4q_1^f$	1.253	1.235	1.149	1.087
Bangladesh	Absolute excess ${}_4q_1^f$	15	9	3	1
Chad	Relative excess ${}_4q_1^f$	1.035	1.028	1.048	1.063
Chad	Absolute excess ${}_4q_1^f$	3	2	4	4
DR Congo	Relative excess ${}_4q_1^f$	1.01	1.021	1.027	1.052
DR Congo	Absolute excess ${}_4q_1^f$	1	2	2	2
Egypt	Relative excess ${}_4q_1^f$	1.106	1.073	1.07	1.111
Egypt	Absolute excess ${}_4q_1^f$	5	1	1	1
India	Relative excess ${}_4q_1^f$	1.44	1.527	1.529	1.513
India	Absolute excess ${}_4q_1^f$	19	15	9	5
Iran	Relative excess ${}_4q_1^f$	1.353	1.242	1.184	1.193
Iran	Absolute excess ${}_4q_1^f$	5	2	1	0
Jordan	Relative excess ${}_4q_1^f$	1.251	1.516	1.94	2.303

Continued...

Country	Indicator	1980-85	1990-95	2000-05	2010-15
Jordan	Absolute excess ${}_4q_1^f$	2	2	2	2
Laos	Relative excess ${}_4q_1^f$	1.082	1.075	1.107	1.172
Laos	Absolute excess ${}_4q_1^f$	5	3	3	2
Malawi	Relative excess ${}_4q_1^f$	1.055	1.042	1.049	1.063
Malawi	Absolute excess ${}_4q_1^f$	6	4	2	1
Mali	Relative excess ${}_4q_1^f$	1.01	0.993	0.977	1.479
Mali	Absolute excess ${}_4q_1^f$	2	-1	-2	16
Nepal	Relative excess ${}_4q_1^f$	1.194	1.208	1.207	1.142
Nepal	Absolute excess ${}_4q_1^f$	13	7	3	1
Niger	Relative excess ${}_4q_1^f$	1.046	1.03	1.02	1.104
Niger	Absolute excess ${}_4q_1^f$	9	6	2	4
Pakistan	Relative excess ${}_4q_1^f$	1.299	1.308	1.263	1.236
Pakistan	Absolute excess ${}_4q_1^f$	11	9	6	4
Sudan	Relative excess ${}_4q_1^f$	1.012	1.028	1.044	1.102
Sudan	Absolute excess ${}_4q_1^f$	1	1	2	3
Syria	Relative excess ${}_4q_1^f$	1.062	1.146	1.192	1.313
Syria	Absolute excess ${}_4q_1^f$	1	1	1	1
Yemen	Relative excess ${}_4q_1^f$	1.064	1.088	1.112	1.185
Yemen	Absolute excess ${}_4q_1^f$	4	3	3	3

Table A.6.2: Significant outlier countries that showed excess female infant mortality (${}_4q_1^f$) from 1980-85 to 2010-15. *Relative* excess female mortality refers to the ratio of lifetable estimated to model-predicted female ${}_4q_1^f$. *Absolute* excess female mortality refers to the difference between lifetable estimates and model-predicted female ${}_4q_1^f$. This is expressed in terms of the deaths per 1000 survivors until age 1.

Country	Indicator	1980-85	1990-95	2000-05	2010-15
Afghanistan	Excess female deaths	22.8	14.7	21.7	22.3
Afghanistan	Missing female births	0	0	0	0
Albania	Excess female deaths	0.9	0.4	0.3	0.1
Albania	Missing female births	0	0	0.5	0.3
Armenia	Excess female deaths	-0.2	0.1	0.1	0
Armenia	Missing female births	-0.4	0.1	4.5	4.5
Azerbaijan	Excess female deaths	0.3	-3.6	2.1	0.2
Azerbaijan	Missing female births	0	0	11.6	21.7
Bangladesh	Excess female deaths	144.4	110.2	62.2	20.9
Bangladesh	Missing female births	0	0	0	0
China	Excess female deaths	240.7	271.7	98.9	44.7

Continued...

Country	Indicator	1980-85	1990-95	2000-05	2010-15
China	Missing female births	0	642.8	1311.2	1790.2
Egypt	Excess female deaths	62.1	37.6	14.7	12.4
Egypt	Missing female births	0	0	0	14
Ghana	Excess female deaths	4	6.9	7.8	5.1
Ghana	Missing female births	0	0	0	0
India	Excess female deaths	1835.2	1882.7	1573.1	920.8
India	Missing female births	0	319.5	1253.8	1536.3
Iran	Excess female deaths	68.2	41.2	12.9	5.8
Iran	Missing female births	0	0	-15.7	0
Iraq	Excess female deaths	6	4.1	9.9	1.7
Iraq	Missing female births	0	0	0	0
Jamaica	Excess female deaths	0.6	0.3	0.3	0.2
Jamaica	Missing female births	0	0	0	0
Jordan	Excess female deaths	1.9	1.2	1	0.5
Jordan	Missing female births	0	0	0	0
Laos	Excess female deaths	2	1.8	2.4	2.3
Laos	Missing female births	0	0	0	0
Lebanon	Excess female deaths	0	0.3	0.3	0.3
Lebanon	Missing female births	0	0	0	0
Madagascar	Excess female deaths	10.8	8.2	4.4	3.1
Madagascar	Missing female births	0	0	0	7.9
Malawi	Excess female deaths	10.3	12.4	11.7	8.9
Malawi	Missing female births	0	0	0	0
Mali	Excess female deaths	6.2	8.6	10.2	16
Mali	Missing female births	0	0	0	0
Morocco	Excess female deaths	11.9	5.7	4.5	1.2
Morocco	Missing female births	0	3.5	8.5	6.9
Nepal	Excess female deaths	35.8	28.2	15.5	5.1
Nepal	Missing female births	0	0	23.8	7.1
Niger	Excess female deaths	15.6	15.6	16.3	12.4
Niger	Missing female births	0	0	0	0
Nigeria	Excess female deaths	25.1	32.5	98.2	184.5
Nigeria	Missing female births	0	0	0	0
Oman	Excess female deaths	0.5	0.5	0.2	0.1
Oman	Missing female births	0	0	0	0
Pakistan	Excess female deaths	123.1	145.3	111.8	89.4
Pakistan	Missing female births	0	0	78.2	119.3
Qatar	Excess female deaths	0.1	0.1	0	0
Qatar	Missing female births	0	0.1	-0.2	-0.2
Saudi Arabia	Excess female deaths	2.8	4.2	5.4	4.1
Saudi Arabia	Missing female births	0	0	0	0
Sudan	Excess female deaths	3.3	7.2	12.4	25.2
Sudan	Missing female births	0	0	0	0

Continued...

Country	**Indicator**	**1980-85**	**1990-95**	**2000-05**	**2010-15**
Tunisia	Excess female deaths	1.6	0.4	1.1	1.2
Tunisia	Missing female births	0	0	0	0
Yemen	Excess female deaths	5.1	8.6	10.8	11.5
Yemen	Missing female births	0	0	0	0

Table A.6.3: Missing female births (calculated from eq. 6.3) and excess female deaths (calculated from eq. 6.4) for countries with infant and child mortality levels indicative of excess female mortality from 1980-85 to 2010-15. All figures are in thousands.

Chapter 7

The Impact of Prenatal Sex Selection on Relative Female Child Mortality

7.1 Introduction

The previous chapter examined changes in prenatal sex selection and postnatal excess mortality in a macro-demographic perspective using country-level lifetable data. Although changes in the fertility component indicative of prenatal sex selection have been larger than changes in the mortality component, patterns of change in excess female mortality in countries that saw the onset of prenatal sex selection varied across countries and by period. In South Korea, reductions in aggregate-level excess female mortality coincided with SRB increases in the 1980s. In India and China, relative excess female mortality was remarkably persistent even as SRB distortions set in, increased and began to stabilise. In the 2000s, changes in the mortality component in India, Nepal and Pakistan suggested slight reductions in excess female mortality, even though levels of excess female mortality continued to remained high in these countries.

This macro-demographic analysis highlighted how each component contributed to overall changes in the child sex ratios. The method used did not permit an assessment of whether changes in prenatal sex selection were responsible for mortality changes. Reductions in excess female mortality could occur independently

of changes in prenatal sex selection, through wider modernisation processes that entail the weakening of son preference. Furthermore, within countries where prenatal sex selection has been noted, the populations that show prenatal and postnatal manifestations of son preference may not overlap. This chapter addresses some of these limitations and explores the relationship between prenatal and postnatal manifestations of son preference using micro-level data on birth histories from the Demographic and Health Surveys (DHS).

7.2 A Recap of Hypotheses

For prenatal sex selection to cause changes in mortality, patterns of disadvantage in female mortality should exist in the populations that experience the uptake of prenatal sex selection. The populations, however, may not necessarily overlap. Within countries, if excess female mortality levels are generally concentrated amongst disadvantaged households, whereas those practicing prenatal sex selection are those that are better off, changes in prenatal sex selection would not be the mechanism causing mortality change due to differential sorting into the two behaviours. Existing literature has highlighted how SRB distortions, at least when SRBs have first become distorted in South Korea and India, have been concentrated amongst tertiary-educated mothers with better access to ultrasound and low fertility norms (Jha et al., 2011; Park and Cho, 1995). The pattern of disadvantage in under-five mortality in South Asia has been shown to follow the opposite pattern with the least educated mothers showing the most distorted sex ratios of mortality (Monden and Smits, 2013).

If differential sorting into the two behaviours is occurring, there will be no effect of prenatal sex selection on postnatal mortality change. At the aggregate level, however, mortality change could nevertheless occur. If girls are increasingly born into disadvantaged households in which son preference is strong and

girls are less likely to be born into better-off households, excess female mortality may potentially worsen due to the negative selection of female births into these households. Conversely, if son preference is weakening faster among groups that do not practice prenatal sex selection either due to lack of ability or willingness to practice prenatal sex selection, excess mortality may decline due to changes in son preference norms and not the uptake of prenatal sex selection.

If son preference remains relatively stable and widespread across different groups, as ultrasound technology and low fertility norms diffuse more widely over time, the impact of prenatal sex selection on mortality change may be greater. In countries of South Asia, where the mortality manifestations of son preference are significant and suggest the presence of strong and stable son preference, the wider diffusion of ultrasound or the desire to reduce overall fertility facilitated by modernisation processes may be faster than reductions in son preference. Here, it is plausible that as ultrasound diffuses beyond the initial pioneer groups of the better educated and becomes more widely available to less educated mothers where patterns of disadvantage in female mortality are concentrated, the uptake of prenatal sex selection would contribute to reductions in female mortality disadvantage.

7.3 Data

This chapter uses data on mortality outcomes from birth histories from the DHS for six countries that have witnessed SRB distortions – India, Nepal, Pakistan, Albania, Azerbaijan and Armenia.[1] The surveys are nationally representative cross-sections of women aged 15-49. Different survey waves are available for each country. For India, three survey waves (1992-93, 1998-99, 2005-06) are available. For Nepal four waves (1996, 2001, 2011), Pakistan three waves (1999-91, 2006-07,

[1]The datasets are downloaded from `http://dhsprogram.com`. DHS data for Vietnam are also available. However, the most recent DHS wave for Vietnam (2002) predates the onset of SRB distortions in that country. Consequently, it is not used in this analysis.

Table 7.1: Descriptive statistics on birth years, births and deaths (0 – 11 months) by Demographic and Health Survey country samples.

Country	Birth Years	Males		Females		Male/Female
		Births	Deaths (%)	Births	Deaths (%)	Mortality Ratio
Armenia	1970-2010	15271	659	13766	494	1.22
			(4.3)		(3.6)	(1.08, 1.38)
Azerbaijan	1973-2006	6922	458	6191	371	1.12
			(6.6)		(6.0)	(0.98, 1.28)
Albania	1976-2009	6305	234	5904	163	1.35
			(3.7)		(2.8)	(1.11, 1.65)
India	1970-2006	387124	31959	357986	27932	1.07
			(8.3)		(7.8)	(1.05, 1.08)
Pakistan	1970-2013	55821	4739	52099	4005	1.11
			(8.5)		(7.7)	(1.07, 1.16)
Nepal	1970-2011	54062	5445	51633	4592	1.11
			(10.1)		(8.9)	(1.06, 1.15)

†Male/Female mortality ratio with 95 % confidence intervals in parentheses refer to male-to-female relative risks estimated from Cox Proportional Hazards models controlling for child's birth year and birth year squared.

2012-13), Albania one wave (2008-09), Armenia three waves (2000, 2005, 2010), and Azerbaijan one wave (2006) are available.

In the birth recode of the DHS for each country, the respondents report on all births they have had. Due to the different ages of the mothers in the survey samples, the birth histories span a number of years. In addition to the children's characteristics, information on the parents' characteristics, such as maternal age, maternal education and paternal education are also available in the survey. As mothers report on all births, information on sibling composition of the family can also be deduced from the birth histories. In contrast to the macro-level mortality analysis of the previous chapter, which examined aggregate patterns of sex ratios of mortality, this data source enables an analysis of mortality patterns by sibling composition. I generate a dataset that pools birth histories across different surveys waves for the six countries totalling a sample of 1,013,084 births that span the period from the 1970s to the mid- to late-2000s for each country (see Table 7.1 and 7.2 for information on the coverage of birth years by country).

Table 7.2: Descriptive statistics on birth years, births and child (12 – 59 months) deaths by Demographic and Health Survey country samples.

Country	Birth Years	Males		Females		Male/Female
		Births	Deaths (%)	Births	Deaths (%)	Mortality Ratio
Armenia	1970-2010	15271	101	13766	59	1.59
			(0.7)		(0.4)	(1.15, 2.19)
Azerbaijan	1973-2006	6922	83	6191	58	1.31
			(1.2)		(0.9)	(0.93, 1.84)
Albania	1976-2009	6305	30	5904	20	1.05
			(0.5)		(0.3)	(0.63, 1.77)
India	1970-2006	387124	9427	357986	11678	0.75
			(2.4)		(3.3)	(0.73, 0.77)
Pakistan	1970-2013	55821	874	52099	976	0.82
			(1.6)		(1.9)	(0.77, 0.93)
Nepal	1970-2011	54062	1813	51633	2121	0.84
			(3.4)		(4.1)	(0.77, 0.93)

†Male/Female mortality ratio with 95 % confidence intervals in parentheses refer to male-to-female relative risks estimated from Cox Proportional Hazards models controlling for child's birth year and birth year squared.

For each birth, information on the date of birth, date of death if the child died, and child's sex are available. Table 7.1 provides information on births and infant (0 – 11 months) deaths by sex for each country. Table 7.2 provides descriptive statistics on child (12 – 59 months) deaths by sex for each country in the dataset.

The data do not allow us to observe which families practiced prenatal sex selection. Instead, to capture changing levels of prenatal sex selection over time within these countries I use data on the SRB across birth years as a proxy for the manifestation of the behaviour. This is similar to the approach adopted by Hu and Schlosser (2015) who used variation in the male-to-female child sex ratio by years across Indian states to capture changes in prenatal sex selection. As discussed in the previous chapter, the child sex ratio is a measure of both prenatal and postnatal manifestations of son preference. Hu and Schlosser (2015) merged interpolated data on the child sex ratio from the 2001 and 2011 Indian Censuses with the Indian DHS birth histories due to limited data, as described in chapter 5, on state-level variations in the SRB over time. They additionally smoothed

SRBs computed from within the pooled Indian DHS birth histories by taking a seven-year moving average.

As the study by Hu and Schlosser (2015) illustrates, the SRB can theoretically be aggregated from the DHS birth histories directly. The Indian DHS however is significantly larger than the other countries in the sample. Due to variations in birth numbers by year within surveys for each country, the SRB generated from within the DHS birth histories fluctuates significantly. Consequently, I merge information on the SRB by country and birth year from the United Nations World Population Prospects (UN WPP) 2015 (United Nations, 2015a) for five of the six countries except Albania. As discussed in the previous chapter, the UN estimates of the Albanian SRB significantly underestimate it. As a result, I use data from the Albanian statistical office on the country's SRB time-series.[2] The UN WPP SRB time-series uses information on vital registration obtained from national statistical offices to generate SRB estimates. When these are deficient or not available, information from censuses or surveys such as the DHS are used, or combined with vital registration estimates, to generate SRB estimates for five-year periods (United Nations, 2015b). Similar to the approach used in chapters 3 and 4, I interpolate between consecutive five-year periods to generate yearly SRB estimates from the UN time-series. The generated yearly SRB trajectories for each of the six countries are depicted in Fig. 7.1. I recode the SRB variable such that a biologically normal SRB under 106 is 0 with each additional, excess male birth coded as 1, 2, 3, and so on.

[2]These data were accessed from `http://www.instat.gov.al/en/themes/population.aspx`.

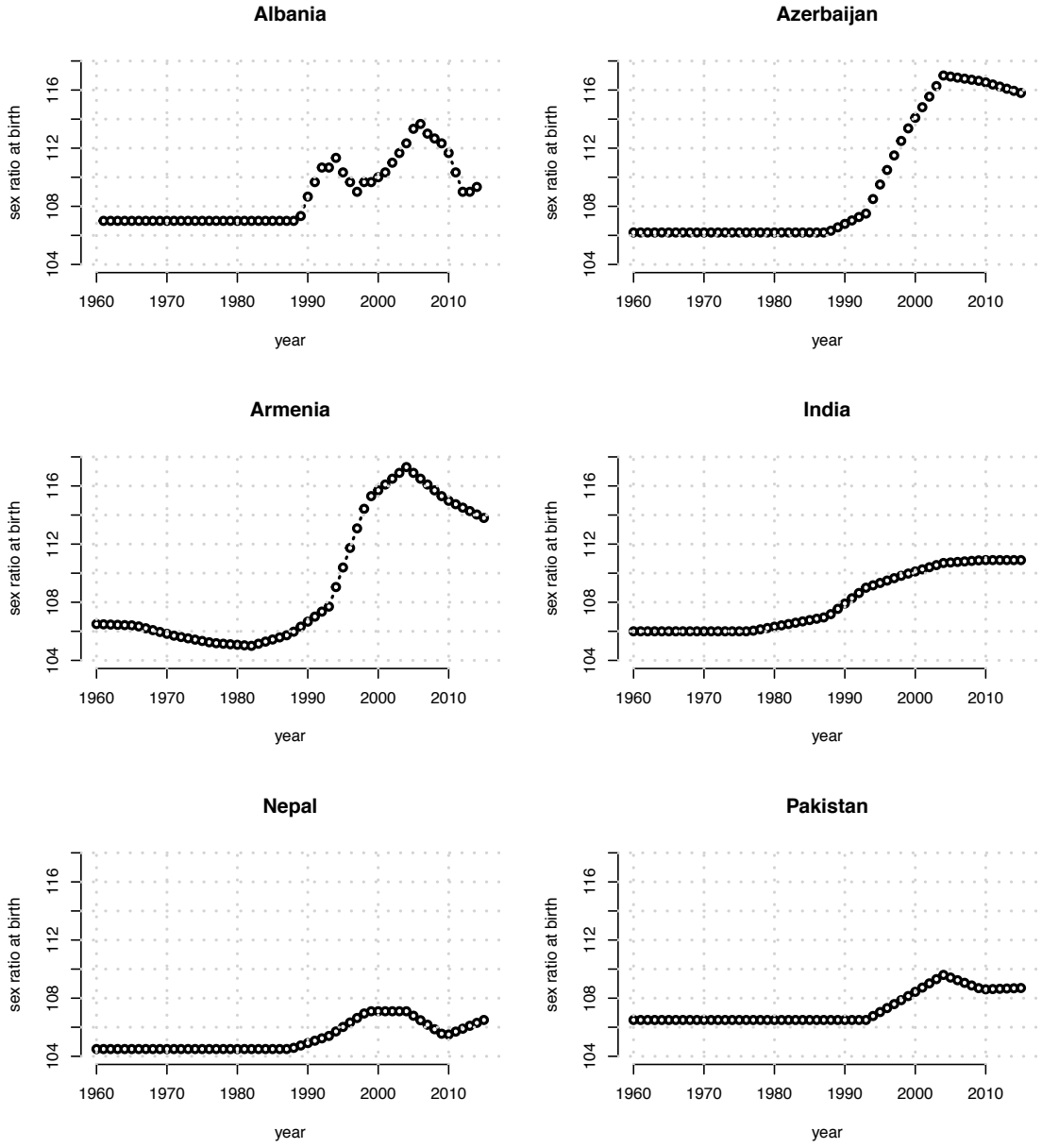


Figure 7.1: Sex ratio at birth (SRB) by birth years for countries in the analysis. Data from UN WPP (2015).

7.4 Statistical Approach

How does prenatal sex selection impact mortality risks for girls who are born? The statistical approach adopted here attempts to isolate the effect of prenatal sex selection, as proxied by changes in the SRB, on mortality risks for girls relative

to boys whilst controlling for confounders that might impact mortality change differentially by sex of the child. In another set of models, I examine the impact of prenatal sex selection on girls of higher birth orders (three and higher) without an older brother relative to girls of higher birth orders with at least one older brother – a subset of girls that literature on South Asia has identified as especially vulnerable to mortality disadvantage (Pande, 2003; Muhuri and Preston, 1991).

The outcome of interest is death of the child reported in the survey in either infant (0–11 months) or in childhood ages (12–59 months). The dataset includes different births born in different years, with differential exposures to the event of interest (death). The most recent births are right censored as they have not been fully observed until the end of the observation window (survey date). The statistical model should account for this right censoring and event history structure of the data. I incorporate a regression approach within an event history framework by using a proportional hazards (PH) model (Cox, 1972). To estimate the impact of prenatal sex selection on girls mortality relative to boys, I estimate the following PH model on the pooled dataset of the six countries:

$$\begin{aligned} h(t, x_{ibc}) = h_0^c(t) \exp(&\text{female}_i\beta_1 + \text{SRB}_b\beta_2 + (\text{female}_i \times \text{SRB}_b)\beta_{12} \\ &+(\text{female}_i \times \text{birthyear}_b)\beta_{13} + x'_{ib}\delta) \end{aligned} \tag{7.1}$$

where $h(t, x_{ibc})$ refers to the hazard of death in the first year of life (infant mortality) or between ages 1 and 5 (child mortality) for a child i, born in year b, and in country c, x'_{ib} is a vector of controls including parental characteristics such as maternal and paternal education, maternal age, maternal age squared, and child characteristics including birth order, birth year, and birth year squared. Due to variations in the birth years covered in each country sample, I centre the birth year variable with a mean of 0 and standard deviation of 1. $h_0^c(t)$ refers to a stratified baseline hazard for each country in the analysis, which is equivalent to including a country fixed-effect that controls for time-invariant country-specific

factors such as variations in levels of overall mortality, levels of development and strength of son preference across these six different countries. The effect of interest is β_{12} that captures the differential impact of SRB change by birth year on the mortality of boys versus girls. In terms of the relative risks framework of the proportional hazards model, the model attempts to identify the effect of prenatal sex selection, as proxied by within-country variation in the SRB by birth years, on the risk of infant and child mortality for girls relative to boys. A main effect for the SRB (β_2) is also included in the model. In addition, β_{13} captures other sex-specific trends in mortality change unrelated to changes in prenatal sex selection. This effect attempts to capture trends in mortality change that differentially affect boys versus girls as separate from changes in the SRB.

The vector of controls includes variables that may independently influence female mortality relative to male mortality. Maternal education has been associated with sex ratios of infant and child mortality (Monden and Smits, 2013). Moreover, children born in later birth years in the sample are more likely to have mothers with higher levels of education than those born in earlier years. Maternal education has been linked with improved outcomes for children (Desai and Alva, 1998), but has also been shown to be associated with weaker son preference norms that result in differential treatment of girls versus boys (Pande and Astone, 2007). Although the effects of paternal education have not separately been explored in the literature, paternal education may have a separate, independent effect on the weakening of son preference norms that result in differential outcomes for boys and girls. Paternal and maternal education jointly also measure family socioeconomic status. Maternal age, maternal age squared and the child's birth order are included as additional control variables in the model. Multiple births by the same mother are included in the dataset. To account for the correlation of observations within families, standard errors are clustered by mother.

To identify the impact of prenatal sex selection on mortality change, the model in eq (7.1) assumes that changes in the SRB within each country over time is unrelated to unobserved factors that might differentially impact the outcomes of girls compared to boys. The vector of control variables attempts to account for these factors. Similarly to the line of reasoning presented in Hu and Schlosser (2015, p. 1245), I also include a main effect for the SRB in all models. The main effect of the SRB should act as an indicator of the effect of unobserved time-varying factors at the country-level that are correlated with the SRB. If the main SRB effect is statistically significant, this would suggest that the vector of controls might not be adequately capturing factors that might have an independent impact on changing sex-differentials in mortality.

This country stratified or country fixed-effects specification in eq. (7.1) estimates an average within-country effect of the increases in excess male births on improvements in the relative risk of female versus male mortality. There could of course be country-level heterogeneity in the effect of prenatal sex selection on mortality change, as described in the previous chapter. This effect might vary by the stage of the demographic transition a country is in, which in turn is related to the strength of son preference in that setting and the extent of female disadvantage in mortality. I also estimate models separately for each country in the dataset to explore potential heterogeneity in this effect. In this case, the models are estimated for the country dataset without the stratified baseline hazard ($h_0^c(t)$).

7.5 Results

The descriptive statistics on births and infant deaths by sex presented in Table 7.1 and child deaths by sex are presented in Table 7.2. The south Asian countries of India, Nepal and Pakistan have higher levels of infant and child mortality

compared to Azerbaijan, Armenia and Albania. Albania has the lowest infant and child mortality levels of the six countries analysed here. Sex ratios of infant mortality are generally higher in all countries than sex ratios of child mortality, with sex ratios of infant mortality lower in South Asia and Azerbaijan compared with Albania and Armenia. Sex ratios of child mortality are particularly skewed in the direction of lower risks of death in childhood ages for boys relative to girls for south Asia. The larger sample sizes in the south Asian (India, Nepal and Pakistan) DHS samples along with with overall higher levels of mortality also allow for greater precision in estimating the sex ratios of mortality for these countries compared to the samples from Albania, Azerbaijan and Armenia.

Table 7.3: Hazard ratios from proportional hazards model with country fixed effects with (1) infant (0 – 11 months) mortality and (2) child (12 – 59 months) mortality as outcome variables.

	Infant Mortality	Child Mortality
female	0.934***	1.281***
	(0.0121)	(0.0304)
SRB	0.992	1.007
	(0.00593)	(0.0128)
female × SRB	0.993	1.012
	(0.00679)	(0.0139)
birth year	0.982***	0.956***
	(0.000960)	(0.00190)
female × birth year	1.002*	1.001
	(0.00103)	(0.00185)
birth year squared	1.000	1.000***
	(0.0000355)	(0.0000693)

Exponentiated coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
†Models control for maternal age, maternal age squared, maternal education, paternal education and birth order.

Table 7.3 reports results from the country-fixed effects specification from eq. (7.1) estimated on the pooled sample of birth histories of the six countries. For both outcomes, infant and child mortality, the main effect of the SRB and the interaction effect for female x SRB are small and are not statistically signifi-

cant. Averaged across the six countries, these results suggests that changes in the SRB for birth cohorts within countries were not systematically associated with differential changes in female relative to male mortality.

Could between country heterogeneity in the impact of SRBs on mortality change account for this? To investigate this, I estimated eq. 7.1 separately for each of the six countries without the country-level fixed effects. The estimates from country-level models for Albania, Azerbaijan, Armenia, Nepal and Pakistan followed the same patterns of the model reported in Table 7.3 with no statistically significant effect on the female x SRB interaction or on the SRB main effect (models not shown).

India, however, was an exception. Table 7.4 shows results from the PH model estimated on the Indian sample of births. For infant mortality, the SRB main effect is not statistically significant but the female x SRB interaction term is. The hazard ratio for the interaction term for infant mortality is 0.96, which indicates that each additional excess male birth in a given year beyond biologically normal levels of 106 was associated with a 4% reduction in the risk of infant death for girls. The effect size for the female x SRB interaction is similar for child mortality but is not statistically significant at the 5% level ($p = 0.054$).[3]

This result for India contrasts with the results of Hu and Schlosser (2015) who found that changes in state-year male-to-female child sex ratios were not statistically significantly associated with a faster reduction in girls' mortality relative to that of boys in India. The finding reported in Table 7.4 exploits variation in the SRB by birth year whereas Hu and Schlosser (2015) relied on variation in the child sex ratio by state and birth year. Additionally, Hu and Schlosser (2015) did not account for right censoring for recent births in their dataset as they estimate a linear probability model instead of a hazard model. Changes

[3]These results are robust to the inclusion of birth year fixed effects instead of a linear term for birth year. Since mortality decline over the birth years in the sample is remarkably linear, I show the linear and quadratic term in tables 7.3 and 7.4. I also estimated these models as linear probability models instead of PH models and found substantively similar results.

Table 7.4: Hazard ratios from proportional hazards model for the Indian sample with (1) infant (0 – 11 months) mortality and (2) child (12 – 59 months) mortality as outcome variables.

	Infant Mortality	Child Mortality
female	1.008	1.478***
	(0.0275)	(0.0656)
SRB	0.996	0.958
	(0.0139)	(0.0248)
female × SRB	0.961**	0.957
	(0.0133)	(0.0222)
birth year	0.981***	0.965***
	(0.00243)	(0.00459)
female x birth year	1.007***	1.010**
	(0.00209)	(0.00332)
birth year squared	1.000	1.000
	(0.0000691)	(0.000138)

Exponentiated coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
†Models control for maternal age, maternal age squared, maternal education, paternal education, birth order and state fixed-effects.

in the child sex ratio are affected by both prenatal and postnatal mechanisms of sex selection. To capture the effects of prenatal sex selection solely, the SRB is a better measure. Nevertheless, by relying on national, aggregate variations in SRB by year in a context where considerable heterogeneity in the onset and levels of SRB distortions exists between states, the estimates may mask the true effect of increases in prenatal sex selection on sex-differentials in mortality. It is plausible, for instance, that patterns of mortality change may be concentrated in regions of the country where SRBs may not have increased. There is a strong regional patterning of son preference in India (Dyson and Moore, 1983). Distorted sex ratios of mortality have been concentrated in areas where subsequent SRB distortions have been noted (Guilmoto, 2009; Bhat and Zavier, 2003).

To further investigate if patterns of change in female mortality relative to male mortality in birth cohorts experiencing prenatal sex selection occurred in son-preferring families, I examined mortality change for girls based on their sibling

composition. The existing literature on South Asia has reported that higher birth order girls, usually at birth orders three and higher, without an older brother fare the worst in terms of survival (Pande, 2003; Muhuri and Preston, 1991). Table 7.5 reports estimates from a proportional hazards model estimated on the sample of female births at birth order three and higher in India. I examined the risks of infant and child mortality for girls without older brothers relative to those with at least one older brother comparing cohorts that experienced prenatal sex selection with those that did not (Girls without older brothers × SRB coefficient). These models show that girls without older brothers do significantly worse than those with at least one older brother. Their risks of infant mortality are 47% higher than those with at least one brother, and risks of child mortality are 14.8% higher. The hazard ratio of under 1 (0.966) for the interaction term involving girls without older brothers × SRB indicates that the mortality gap between higher birth order girls without older brothers and those with at least one older brother narrowed for cohorts that experienced prenatal sex selection. Although mortality patterns by sibling composition showed similar disadvantage for girls without older brothers in Nepal, Pakistan, Azerbaijan, Albania and Armenia (see discussion of these patterns later in the chapter), the interaction of sibling composition with SRB was not statistically significant in these five countries.

7.5.1 Differential Sorting

These results suggest that changing SRB trends indicative of prenatal sex selection were not systematically associated with changes in patterns of girls' mortality, either relative to boys' mortality or for the subset of girls without an older brother relative to those with an older brother, for five of the six countries analysed here with the exception of India. One plausible explanation for the lack of a statistically significant result may lie in limited statistical power of the small samples sizes of the survey data to capture trends in sex-differentials in mortality,

Table 7.5: Hazard ratios from proportional hazards models estimated on sample of female births of birth orders three and higher in India with (1) infant (0 – 11 months) mortality and (2) child (12 – 59 months) mortality as outcome variables.

	Infant Mortality	Child Mortality
Girls without older brothers	1.471***	1.148***
	(0.0438)	(0.0480)
SRB	0.975	0.909*
	(0.0255)	(0.0353)
Girls without older brothers × SRB	0.966*	0.973
	(0.0144)	(0.0228)

Exponentiated coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
†Models control for birth year, birth year squared, maternal age, maternal age squared, maternal education, paternal education, birth order and state fixed-effects.

particularly in the samples of Albania, Armenia and Azerbaijan where mortality levels are lower than in South Asia and sample sizes are smaller.

However, another plausible explanation may lie in patterns of differential sorting into prenatal and postnatal sex selection. If those populations that practice prenatal sex selection are separate from those where postnatal manifestations of son preference in the form of female mortality disadvantage are concentrated, patterns of mortality disadvantage may remain unchanged or be driven by other factors unrelated to the uptake prenatal sex selection. To examine the potential contribution of differential sorting into prenatal and postnatal mechanisms of sex selection, in this section I study variations in the sex ratios at birth and of mortality based on existing family composition and by maternal education. SRB estimates calculated from survey-based birth histories are highly sensitive the number of births recorded in the sample (Arnold et al., 2002). For example, an SRB of 110 calculated using survey data with a sample of 5000 births has a 95% confidence interval of 105 to 117. Even though the point estimate is higher than normal SRB levels, the confidence interval does not allow for the rejection of the null hypothesis that the SRB is different from 105. In order to capture variations in the SRB more precisely, I focus on groups of women who

are most likely to practice sex-selective abortion due to their family composition by examining births at higher birth order in those families without existing sons. Similarly, patterns of change in mortality may be masked when examining boys versus girls rather than specific subsets of girls who may be more at risk than others for excess mortality risks.

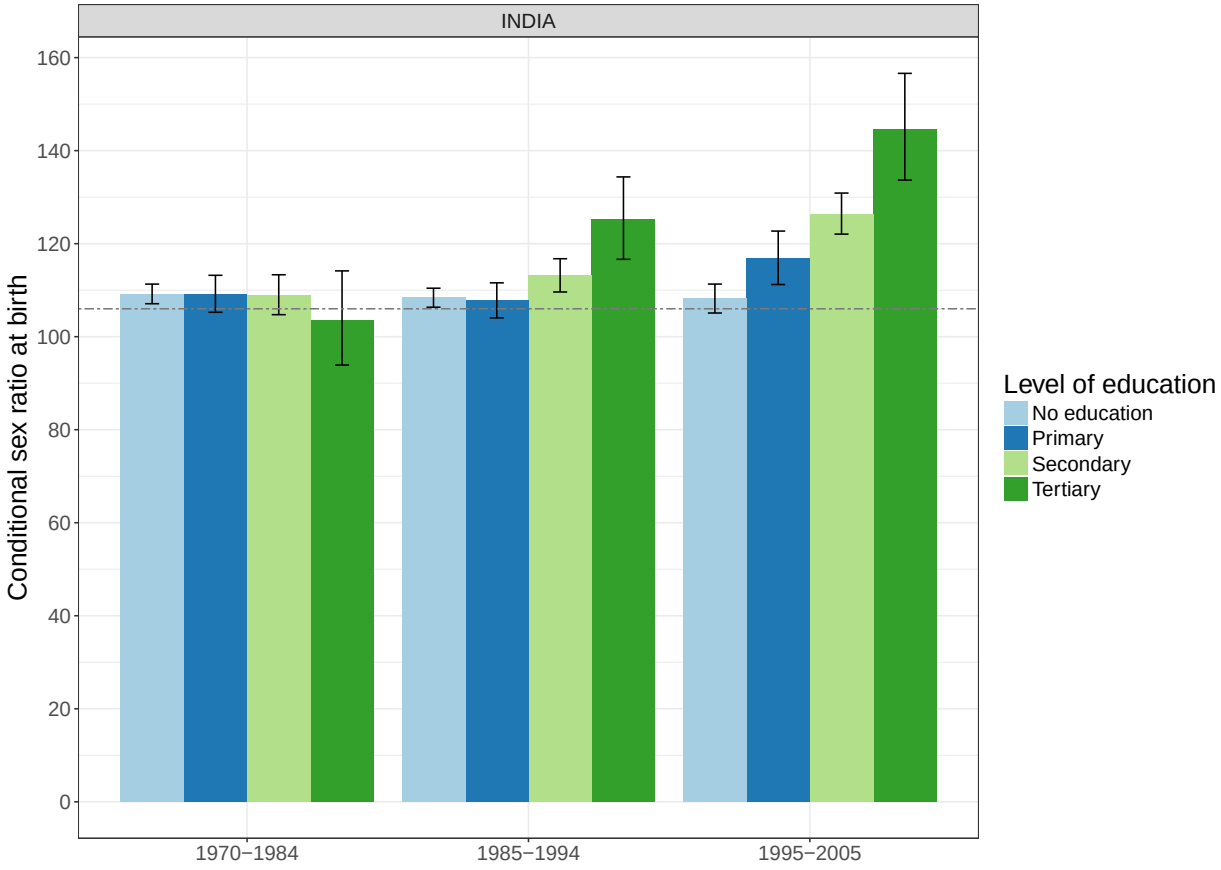


Figure 7.2: Conditional sex ratio at birth (SRB) for second and higher-order births for mothers without a son by level of maternal education and birth years, India. Bars indicate 95% confidence intervals of the conditional SRB estimate.

Fig. 7.2 shows the conditional SRB for second and higher order births for mothers who did not have a son by maternal education and the child's birth year for India. The large sample sizes of the Indian data enable disaggregation into three periods – 1970 – 1984, 1985 – 1994, and 1995-2005. The first period comprises birth years before the onset of prenatal sex selection in India due to the lack of ultrasound technology. The second period, 1985–1994, comprises

birth years when SRB distortions were first noted and ultrasound is assumed to have become available. The third period starting the mid-1990s to the most recent birth years available in the survey corresponds to the period when SRBs gradually showed stabilisation, suggesting a wider diffusion of ultrasound in the population. The dotted horizontal line in figure notes a biologically normal SRB level of 105, corresponding to a probability of male birth of 0.512.

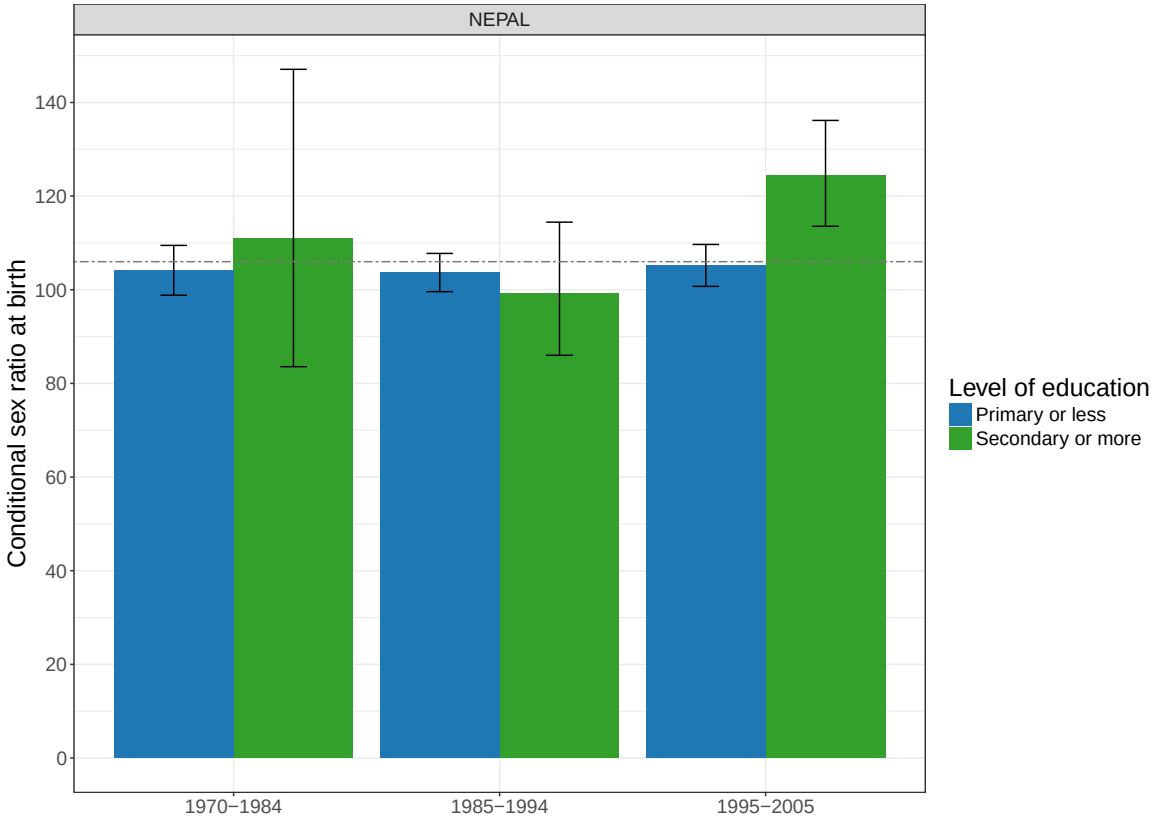


Figure 7.3: Conditional sex ratio at birth (SRB) for second and higher-order births for mothers without a son by level of maternal education and birth years, Nepal. Bars indicate 95% confidence intervals of the conditional SRB estimate.

The same conditional SRB indicator is shown for the Nepalese data in Fig. 7.3. The conditional SRBs followed a common pattern in both South Asian countries. Probabilities of male births at higher birth orders were the highest for better-educated mothers, especially those with tertiary-education. In 1970-1984, SRBs were within biologically normal ranges for all mothers. SRB distortions emerged, first in India in the 1985-1994 period and later in Nepal, in the third, post-1995

period, which also corresponds with the general country-level SRB trajectories highlighted in Fig. 7.1. In the early diffusion period in India (1985-1994) SRB distortions appeared among the tertiary- and secondary-educated and then by the second period, showed a gradual diffusion to primary-educated mothers as well, alongside increases among the tertiary- and the secondary-educated. This pattern suggests a gradual diffusion of prenatal sex selection to a wider population as ultrasound access diffused and low fertility norms became more widespread intensifying the readiness to abort in the absence of a son. The most significant distortions were concentrated amongst tertiary-educated mothers who had conditional SRB values approaching 140 male births per 100 female births in families without a son, suggesting that these mothers were the ones – to use the RWA framework presented in Part I of the thesis – most able and ready to abort.

In Nepal, compared with mothers with primary-level or less education, tertiary-educated mothers showed higher probabilities of male births conditional on not already having a son that exceeded biologically normal levels. The group of tertiary-educated mothers in Nepal was considerably smaller than India and estimates for the tertiary-educated group are less precise. Due to smaller sample sizes in the Nepalese surveys, I present variations across two groups – mothers with primary education or less, and those with secondary education or more. Interestingly, the DHS birth histories for Pakistan did not indicate the same patterns of SRB distortions at higher order births as indicated in the Indian and Nepalese data. This finding concurs with recent work by Zaidi and Morgan (2016) who also used three waves of the DHS for Pakistan. The authors did not find systematically elevated SRBs in the five-years preceding the survey across all three survey waves. Although SRB estimates from the survey data were slightly elevated in the five-year period preceding the 2007 survey, the null hypothesis that the SRB is within biologically normal levels could not be rejected.

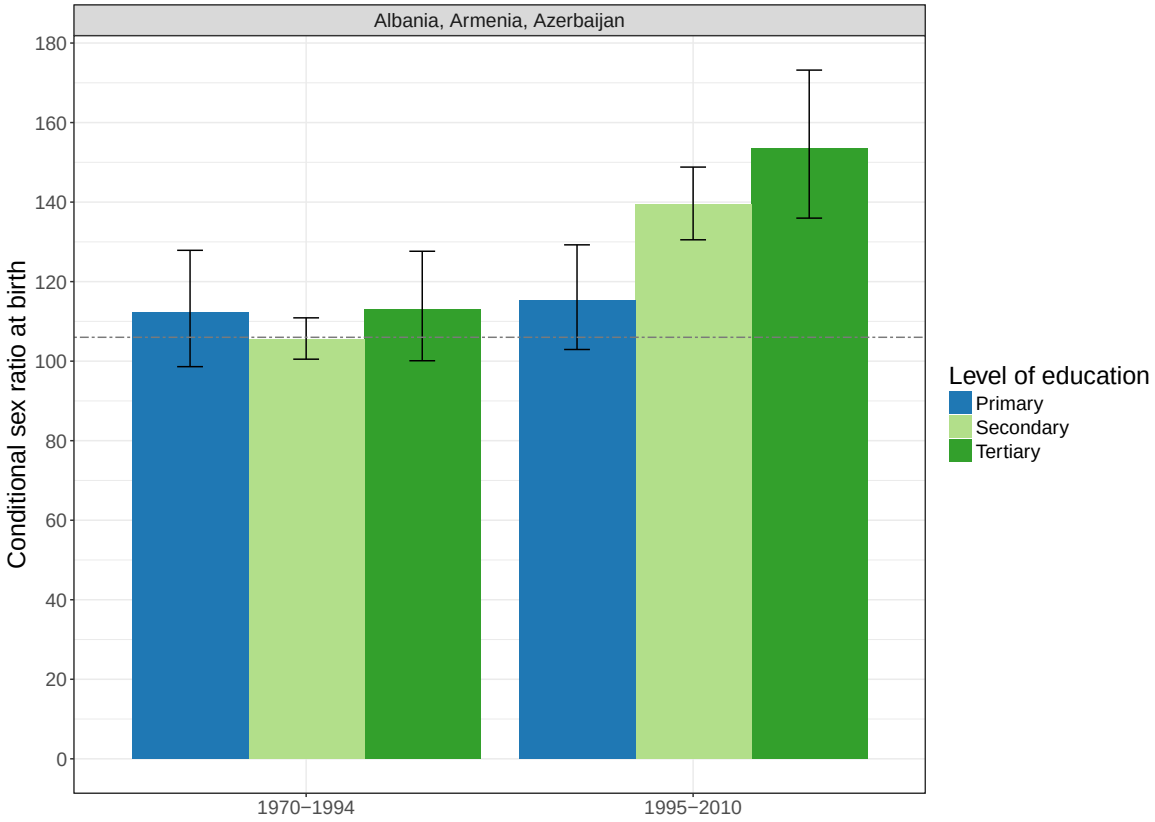


Figure 7.4: Conditional sex ratio at birth (SRB) for second and higher-order births for mothers without a son by level of maternal education and birth years, Albania, Azerbaijan and Armenia. Bars indicate 95% confidence intervals of the conditional SRB estimate.

In Albania, Armenia and Azerbaijan, patterns in SRB distortion by maternal education were similar with tertiary-educated mothers showing the most distorted SRBs in the absence of a son. Due to smaller sample sizes of births in these countries compared with the South Asian ones, I pooled data for all three countries into two periods – 1970-1994, and the period post mid-1990s, when SRB distortions appeared at the aggregate national-level in these countries as shown in Fig. 7.1, to the most recently available birth years in the data. The educational distribution in these three countries has more highly educated mothers than those in South Asia. In the Armenian sample less than 2% of mothers have primary or lower level of education, and 24.5% have a tertiary degree. In Azerbaijan, less than 3% have primary or lower level of education and 8.6% have tertiary educa-

tion. In contrast, mothers in the Albanian sample have on average lower levels of education with 58.2% of mothers with primary or lower level of education, and 7% with tertiary education. For the least-educated mothers, probabilities of male births conditional on not having a son did not change across the two periods and were within biologically normal levels.

These findings suggest that prenatal sex selection over the period under consideration has been largely practiced by highly-educated mothers. This has previously been reported in the literature on India and South Korea, but is noted here also for Nepal, Albania, Armenia and Azerbaijan. Over time in India, a pattern of diffusion of prenatal sex selection to secondary- and primary-educated mothers also emerged in the period after the mid-1990s.

Table 7.6: Relative risks of under-five mortality for higher birth order girls without brothers compared with higher birth order girls with at least one brother, 1970-1994 and 1995-mid 2000s.

	1970–1994	1995–mid 2000s
India	1.32***	1.17***
	(1.28, 1.36)	(1.07, 1.27)
Nepal	1.17***	1.06
	(1.07, 1.28)	(0.88, 1.29)
Pakistan	1.43***	1.31**
	(1.26, 1.64)	(1.14, 1.51)
Albania, Armenia, Azerbaijan	1.15	0.98
	(0.89, 1.48)	(0.67, 1.84)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
†Relative risks are estimated from proportional hazards model with controls for birth year, birth year squared, birth order, maternal age, maternal age squared and paternal education.

How do patterns of female disadvantage in mortality vary by country and among which groups are patterns of mortality disadvantage concentrated? To capture patterns of mortality disadvantage for girls, I examined risks of under-five mortality for higher birth order girls (three and higher) without an older brother relative to higher birth order girls with at least one older brother.[4] These

[4]Due to the overall lower fertility in Albania, Azerbaijan and Armenia compared with the South Asian samples, I estimated the proportional hazards model for girls of birth order two and higher.

relative risks are estimated from four PH models, one each for India, Nepal, Pakistan, and a pooled model for Albania, Azerbaijan and Armenia, on a sample of higher order female births. In addition to the main effects of interest for sibling composition, period and their interactions, the estimated model included controls for birth year, birth year squared, birth order, maternal age, maternal age squared, maternal and paternal education. To capture trends in mortality disadvantage broadly coinciding with a pre- and post-SRB distortion period, I disaggregated births into two periods – 1970–1994 and the second corresponding to births from 1995 to the mid-2000s. These results are reported in Table 7.6.

In all three South Asian countries in the first period, girls without brothers had a higher risk of under-five mortality than those with at least one older brother. In India, girls had a 32% higher risk than girls with brothers, in Pakistan this effect was 43%, and in Nepal this was 17%. In the second period after the mid-1990s, this disadvantage diminished for India to 17%, and interaction term for period x sibling composition is also statistically significant ($p = 0.02$). In Nepal, the disadvantage for higher birth order girls without brothers is not statistically significant in the period after the mid-1990s. The interaction term of sibling composition with period is also not statistically significant, however, indicating the null hypothesis that no change occurred across the two periods cannot be rejected. In Pakistan, the effect size of the disadvantage for girls without brothers appears to diminish after the mid-1990s from 1.43 to 1.40, but the effect is not statistically significant, as indicated by the overlapping confidence intervals of the two period estimates. In Albania, Azerbaijan and Armenia, the effect for disadvantage for girls without brothers is not statistically significant in either period.

To examine in which groups patterns of mortality disadvantage are concentrated, I further disaggregated patterns of disadvantage for higher birth order girls without older brothers relative to those with at least one brother by ma-

ternal education. Results are disaggregated across four categories of maternal education in India due to larger sample sizes for each group. For the other countries, due to smaller sample sizes, results are reported across two categories of maternal education – those with primary or less and those with completed secondary or higher. Table 7.7 highlights under-five mortality risks for girls without an older brother compared to girls with at least one older brother born in the period broadly preceding SRB distortions in the countries, 1970–1994. In contrast to patterns of prenatal sex selection that were concentrated among the more educated, patterns of mortality disadvantage in the pre-SRB distortion period were concentrated amongst less educated mothers. In India over this period, excess mortality for girls without older brothers existed in all three educational groups except among tertiary-educated mothers, for whom the relative risk of girls without older brothers was not statistically significantly higher than those with at least one older brother. Girls without an older brother born to less than primary and primary educated mothers had around 30% excess risk of death compared to those with at least one brother. Similarly, in the other five countries, mothers with a secondary or higher-level of education did not indicate excess mortality risks for girls without a brother.

Across the different countries witnessing SRB distortions studied here, with the exception of India, these results suggest that the groups that experienced mortality disadvantage for girls were different from those that experienced distorted sex ratios at birth indicative of prenatal sex selection. In Nepal, Albania, Azerbaijan and Armenia, SRB distortions were concentrated among highly educated mothers whereas mortality disadvantages for girls were concentrated amongst least educated mothers. In India, excess mortality was more widespread and evident even among mothers with secondary-level education. SRB patterns shown in Fig. 7.2 showed a diffusion of prenatal sex selection across different social groups in the 1995-2005 period, including among those where patterns of

Table 7.7: Relative risks of under-five mortality for for higher birth order girls without brothers compared with higher birth order girls with at least one brother by maternal education, 1970–1994.

	Less than primary	Primary	Secondary	Tertiary
India	1.30***	1.32***	1.20***	1.04
	(1.27, 1.35)	(1.22, 1.41)	(1.10, 1.33)	(0.74, 1.45)

	Primary or less	Secondary and more
Nepal	1.15***	1.50
	(1.07, 1.24)	(0.86, 2.61)
Pakistan	1.43***	1.14
	(1.28, 1.61)	(0.71, 1.78)
Albania, Armenia	1.82*	1.00
and Azerbaijan	(1.11, 3.03)	(0.83, 1.21)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

†Relative risks are estimated from proportional hazards model with controls for birth year, birth year squared, birth order, maternal age, maternal age squared and paternal education.

excess mortality was evident in the period before SRB distortions emerged (see Table 7.7).

Table 7.8 reports results on patterns of mortality by sibling compositions for girls born after the mid-1990s. Excess mortality for girls without brothers persisted amongst the least educated in India and Pakistan, but excess mortality risks for girls without an older brother were not statistically significant in the period after the mid-1990s in Nepal. The excess mortality for girls without an older brother amongst primary- and secondary-educated mother in the 1970–1994 period became weaker and lost statistical significance in the period after the mid-1990s indicating overall improvements in their survival. In India, excess mortality risks for girls without an older brother were also no longer statistically significant in the period after the mid-1990s for primary and secondary-educated mothers. Excess mortality persisted in the group of less educated mothers in Albania, Azerbaijan and Armenia, although the effect size was imprecise as indicated by the wide confidence intervals due to the smaller death counts in these three countries.

Table 7.8: Relative risks of under-five mortality for for higher birth order girls without brothers compared with higher birth order girls with at least one brother by maternal education, 1995–mid 2000s.

	Less than primary	Primary	Secondary	Tertiary
India	1.20***	1.19	1.12	1.48
	(1.09, 1.34)	(0.94, 1.53)	(0.86, 1.44)	(0.47, 4.67)

	Primary or less	Secondary and more
Nepal	1.05	1.41
	(0.86, 1.28)	(0.51, 3.89)
Pakistan	1.40***	1.27
	(1.21, 1.63)	(0.82, 2.28)
Albania, Armenia	1.81*	1.06
and Azerbaijan	(1.01, 3.25)	(0.78, 1.45)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

†Relative risks are estimated from proportional hazards model with controls for birth year, birth year squared, birth order, maternal age, maternal age squared and paternal education.

7.6 Conclusion

Part III of this thesis has examined the relationship between prenatal sex selection and postnatal excess mortality. I first studied the relative contribution of prenatal sex selection and postnatal excess mortality to child sex ratio changes in a macro-demographic study in chapter 6. Drawing on country-level lifetable data from the 1980s onward, I found that the contribution of prenatal sex selection to missing girls in population structures increased across all countries that saw the emergence of prenatal sex selection. Relative excess female child mortality, as revealed by outlying macro-level sex ratios of mortality, persisted in some of these contexts but not in others. In contexts such as South Asia, in India, Pakistan and Nepal, where excess female mortality levels were high, reductions in excess female mortality occurred slowly even as SRBs increases in the 1980s and 1990s. By the 2000s, gradual reductions in excess female mortality occurred in these countries. In contrast, in contexts such as South Korea, reductions in excess female mortality occurred alongside increases in prenatal sex selection in the 1980s.

Although the macro-level analysis revealed country-level variations in the shifting contribution of prenatal and postnatal manifestations of son preference since the 1980s, it did not address whether changes in prenatal sex selection were driving mortality changes. Furthermore, patterns of mortality disadvantage underpinning distorted sex ratios of mortality were not discernible with macro-level mortality data. To address this, this chapter used a different data source – birth histories from the Demographic and Health Surveys of six countries – India, Nepal, Pakistan, Albania, Armenia and Azerbaijan to see if changes in SRBs by birth years within countries explained changes in sex-differentials in mortality. In addition to studying sex-differentials in mortality across countries, these data permitted an analysis of patterns of female mortality disadvantage by sibling composition, such as the excess risks faced by girls with or without brothers. In India, increases in prenatal sex selection as proxied by increases in the SRB were associated with faster reductions in girls infant mortality relative to boys. In particular, girls without an older brother at higher birth orders witnessed faster improvements in their survival chances. In other countries, prenatal sex selection was not associated with sex-differential mortality change. I then examined potential reasons for the lack of a relationship between prenatal and postnatal mechanisms and explored the role of differential sorting into prenatal and postnatal mechanisms of sex selection. These data revealed that prenatal sex selection across these different countries was largely practiced by highly-educated mothers, whereas patterns of mortality disadvantage existed among the less educated.

As shown in Chapter 6, levels of aggregate excess female mortality in the Albania, Armenia and Azerbaijan were lower than those in South Asia. This pattern was also evident in the patterns of mortality disadvantage by sibling composition in each of these countries. Mortality disadvantage for higher birth order girls without an older brother was significant in India, but also in Pakistan and Nepal. Why then was the effect of prenatal sex selection different in India

compared with its neighbours, Nepal and Pakistan? The evidence for prenatal sex selection in Pakistan based on the DHS birth histories was weak. Although UN estimates report slightly elevated SRB levels of 107, uptake of prenatal sex selection was likely relatively low in Pakistan. In Nepal, on the other hand, evidence for prenatal sex selection was clearer. Nevertheless, prenatal sex selection was confined to the most-educated mothers and does not appear to have diffused to other groups to the extent that it has in India. Patterns of female mortality disadvantage were also weaker in Nepal compared with India. In India, even girls born to secondary-educated mothers without an existing son had higher risks of death than those with a son in the period preceding the mid-1990s. In contrast, patterns of mortality disadvantage were confined to less educated mothers. In terms of the intensity of son preference, India is likely to have the strongest levels of all countries analysed here. Perhaps the closest analogue to the Indian case, where similar patterns of change between prenatal and postnatal mechanisms may be expected is in China. DHS data for China are unfortunately not available and similar analyses in the future should seek to investigate the relationship between prenatal and postnatal mechanisms in the country with other data sources.

This analysis itself cannot reveal why less educated mothers did not witness SRB distortions. If it is driven by a limited availability of ultrasound, then it is plausible that increasing access to ultrasound amongst those without access to it may result in reductions in female mortality disadvantage as results from India suggest. However, the limited uptake of prenatal sex selection among this group may reflect lower levels of readiness due to the acceptance of larger family norms as the alternative path to achieving son preference. In this case, excess mortality is likely to come about as a consequence of these higher fertility behaviours. The erosion of son preference norms that accompany the fertility transition in the population is likely to drive changes in excess mortality instead of the substitution of postnatal excess mortality by prenatal sex selection.

Chapter 8

Conclusions

8.1 Contributions

The first two parts of this thesis addressed the phenomenon of prenatal sex selection and its demographic manifestation in sex ratio at birth (SRB) distortions. Parts I and II of the thesis also exploited the potential of computational approaches – both as a set of methods in the form of individual-based simulation techniques (Part I, chapters 2–4) or as novel sources of data (Part II, chapter 5) – for the study of an important demographic topic. Part I sought to characterise macro-level SRB distortions in terms of a general behavioural model of the decision to practice prenatal sex selection – ready, willing and able (RWA). The RWA model was implemented within a microsimulation that highlighted how the three common processes of individuals having a preference for a son (willing), gaining access to prenatal sex determination technology (able), and feeling social pressure to abort instead of proceeding to higher births due to a fertility squeeze (ready) can generate distorted SRB trajectories that can take different levels and shapes.

By aggregating macro-level SRB trajectories from the bottom-up by modelling individual-level behaviours, calibration of the model to national-level South Korean and Indian trajectories highlighted how macro-level patterns of change can often obscure underpinning micro-level dynamics. Notably the model demon-

strated how weakening son preference was reconcilable with increasingly distorted, masculinising SRBs in both countries. Despite weakening son preference, SRB distortions emerged most significantly due to diffusion of ultrasound in combination with growing propensities to abort due to declining overall levels of fertility. The shape of SRB trajectories were especially sensitive to the timing of technology diffusion. In South Korea, SRBs rose earlier than in India due to earlier technology diffusion, and SRBs attained higher levels than in India due to plausibly higher levels of the fertility squeeze that engendered a higher readiness to abort. The readiness to abort parameters in the model accounted for nearly 50% of the variation in the maximum SRB levels attained in the population.

The chapters in Part I of the thesis extended insights on the micro-dynamics on son preference, technology diffusion and fertility decline underlying macro-level SRB trajectories. Even though, as Guilmoto (2009) has argued, existing data preclude a "more detailed decomposition...of these distinct dimensions" in explaining observed SRB levels and trends, by incorporating available data on fertility preferences and demographic rates into a semi-artificial population, the microsimulation model developed in this thesis was able to inform our theoretical intuitions about what patterns of individual-level behaviours describe SRB patterns. The sensitivity analysis of the simulation model drew on metamodelling approaches used in the theory and design of computer experiments (Santner et al., 2003). These approaches allowed for a systematic study of how model outcomes respond to variations in different parameters and their interactions.

Part II of this thesis exploited a novel source of data – web data on the Indian population's search footprints – to indirectly estimate the SRB. Chapter 5 of the thesis used information on Google search volumes related to ultrasound and sonography, both at the national level and at the level of Indian states, to assess whether these data track the regional and temporal dynamics of SRBs. For the 2011–2014 period, states with distorted SRBs tended to display a relatively

high search activity for ultrasound. Drawing on between-state variation in ultrasound search intensity for the period between 2011 and 2013, we 'now-casted' the 2014, 2015 and 2016 SRBs using Google search data. For 2014, due to availability of civil registration data, we were able to compare predictive performance of the model informed by search data with that of lag models. For wealthier states with better birth registration, Google search performed better than lagged variable models in predicting the SRB, highlighting its potential role for indirect demographic estimation. For poorer states with less adequate birth registration, Google search performed worse than lag models but overall model performance for all models was worse for these states. By analysing a population's search footprints, chapter 5 exemplified how big data can be used to study behaviours that are not readily measured, and to supplement existing but often slower or incomplete data sources (e.g., census or civil registration data) in the developing world with more 'real-time' information.

The two empirical studies presented in chapters 6 and 7 in Part III of the thesis contributed to a burgeoning literature studying the relationship between prenatal sex selection and postnatal excess female mortality. Chapter 6 developed a straightforward formal demographic approach for decomposing changes in child sex ratios in populations into two components – a fertility component attributable to prenatal sex selection and mortality component attributable to sex-differentials in mortality. This chapter further drew on existing macro-demographic approaches for quantifying excess mortality for girls relative to boys. Levels of excess female child mortality varied considerably across different contexts where SRB distortions have emerged. South Asia, in particular India, had the highest levels of excess female mortality, followed by China and then the Caucasus, where in general, excess female mortality levels were low. In the most recent decade for which data were analysed between 2000-05 to 2010-15, mortality components appeared to show faster improvements for girls relative to boys in all South Asian

countries, as the fertility component indicated a wider uptake of prenatal sex selection. Similar patterns of change in the direction of faster improvements in the mortality component for girls were also visible in the overall lower mortality contexts of South Korea, Armenia and Azerbaijan as the fertility component increased in these populations. In China, the mortality component continued to indicate excess female mortality and did not show faster improvements for girls, even as SRBs became increasingly masculine.

Chapter 7 addressed the relationship between prenatal sex selection and postnatal excess mortality using a different data source, micro-level birth histories from the Demographic and Health Surveys for six countries – India, Nepal, Pakistan, Azerbaijan, Armenia and Albania. Although these countries represent populations at different stages of the demographic transition with varying levels of mortality and fertility, they have all witnessed the emergence of SRB distortions, with SRB trajectories showing anomalous increases. There are a handful of micro-level studies looking at the impact of prenatal sex selection on mortality change, but these have focused on individual country contexts. This study in comparison to those analysed several countries in a comparative perspective.

In contrast to Chapter 6 that used macro-level lifetable data to describe changes in child sex ratios through changes in the constituent fertility and mortality components, chapter 7 embedded the lifetable approach within a regression framework using the proportional hazards model (Cox, 1972). The statistical approach in this chapter examined if differential mortality change by sex could be explained by the uptake of prenatal sex selection within six different countries where SRB distortions have emerged. In terms of the relative risks framework of the proportional hazards model, the model attempted to identify the effect of prenatal sex selection, as proxied by within-country variation in the SRB by birth years, on the risk of infant and child mortality for girls relative to boys. The birth history data, moreover, enabled an analysis of mortality patterns by

sibling composition and variations in patterns of female mortality disadvantage by maternal education.

Across these six countries, girls at higher birth-order without brothers had higher risks of under-five mortality than those with at least one older brother. However, this pattern of disadvantage varied by maternal education. In general, less educated mothers had the most significant patterns of disadvantage, whereas secondary- and higher-educated mothers did not show higher risks for girls without older brothers relative to girls with at least one brother. An exception here was India, where mortality disadvantage was more widespread and even secondary-educated mothers showed a gap in survival chances for girls with brothers compared with those without brothers.

Did changes in prenatal sex selection impact the survival chances of girls relative to boys, or reduce the patterns of disadvantage for girls without brothers relative to those with brothers? The proportional hazards model suggested that prenatal sex selection independently contributed little to mortality change across all of these countries – with the exception of India. In India, increases in the SRB explained faster reductions in girls infant mortality relative to boys. In particular, birth cohorts that witnessed the uptake of prenatal sex selection saw a closing of the mortality gap between girls with at least one brother and those without a brother.

Why was the effect of prenatal sex selection weak in explaining mortality change? I proposed a hypothesis of differential sorting into prenatal and postnatal patterns of sex selection as a potential explanation. Although patterns of mortality disadvantage were concentrated amongst less educated mothers, patterns of prenatal sex selection were strongest among the most-educated. This finding was remarkably consistent across the different countries in the analysis. The differential sorting of the two behaviours across separate groups offered a likely explanation for why the effect for prenatal sex selection was weak in all

contexts except India. In India, prenatal sex selection in the period after the mid-1990s was practiced even by the primary and secondary-educated groups where mortality disadvantage was also concentrated.

8.2 Limitations and Extensions

In this section, I reflect on limitations of the studies presented in this thesis, potential extensions to address these limitations as well as gaps that remain in the literature. Furthermore, I discuss the ways in which insights presented in the three parts of the thesis, although developed as distinct ideas over the course of writing it and presented as separate studies, could help inform each other in future demographic research on the topic.

8.2.1 The Dynamics of Son Preference

This thesis was motivated by a desire to better understand one of the "most notable anomalies of contemporary demography" – the rise and spread of SRB distortions across several countries in South, East and West Asia, as well as the Balkans. Through the clever interpretation of birth statistics, the discovery by demographers that SRB distortions indicated the practice of prenatal sex selection has been one of the most important contributions of the field in recent decades. As a result, the SRB, previously confined largely to the curiosity of demographers, has become a widespread indicator of gender inequality. Despite the accumulation of literature on SRB patterns, the micro-level dynamics of son preference that underlie macro-level patterns of SRB change have received comparatively less attention. These micro-dynamics are important to interpret the SRB in a nuanced manner and unpack to what extent changes in SRBs indicate worsening patterns of gender preferences and gender inequalities, and to what extent they reflect the interplay of others forces of technology diffusion and fertility decline. A

significant insight demonstrated by the RWA simulation model developed in this thesis is that differing rates of change and the interactions of these disparate forces can result in the varying macro-level SRB trajectories. Son preference has been plausibly declining even as SRBs have become more masculine.

The model in its current form, however, does not attempt to explain why and how son preference changes over time. In part, this decision was motivated by the fact that the literature on the forces shaping the weakening of son preference remains inconclusive. Chung and Das Gupta (2007a) found period effects to be stronger than cohort effects in explaining the decline of son preference in South Korea. What drove these period changes? The aforementioned authors argued that "cumulative social change" associated with modernisation processes of industrialisation and urbanisation weakened son preference "sharply across all age groups and socioeconomic groups in Korea" (Chung and Das Gupta, 2007a, p. 765). The organisation of urban life weakened the dependence on patrilineal and patrilocal family systems for which sons are imperative as forms of economic support and social prestige. Combined with legal changes such as family reforms in 1990 that allowed for greater gender equality in inheritance law, these forces, they argued, resulted in the precipitous decline in son preference measures as shown in the Korean family surveys.

Other scholars such as Echávarri and Ezcurra (2010) have suggested that changes in education, and in particular expansion of female education, may have an important role to play in the weakening of son preference. Although, as shown in this thesis in chapter 7 as well as in other studies such as Jha et al. (2011) and Retherford and Roy (2003) for India, highly-educated women have more distorted SRBs indicating a greater likelihood to practice sex-selective abortion. This has been attributed to better access to technologies such as ultrasound for this group rather than stronger son preference (Guilmoto, 2015). Echávarri and Ezcurra (2010) found an inverted U-shape relationship between district-level

literacy levels and the SRB in India. This result suggests that the transformation of son preference brought about by educational expansion may become stronger as a sufficiently greater fraction of the population becomes educated. Other research on the developing world has suggested the importance of community-level effects of education as separate from individual-level effects of maternal education in explaining lower overall levels of fertility (Kravdal, 2002) as well as lower levels of child mortality (Kravdal, 2004).

These findings about community-level effects of education or threshold effects of education suggest that perhaps forms of social learning or social feedback mechanisms could be at work in explaining the weakening of son preference norms. The exact nature and forms of these mechanisms, as well as the geographical contexts in which they may operate, remains an open question. Future research in the field should seek to address which factors and mechanisms are guiding change in son preference over time. In particular, qualitative research may help inform a deeper understanding of more precise mechanisms driving change in son preference norms, which can then be incorporated within the RWA simulation model.

8.2.2 The Future Course of Sex Ratio at Birth Trajectories

Will the turnaround witnessed in South Korean SRB trajectories similarly ensue in the other contexts where SRB distortions have also emerged? Will countries in Africa where son preference has been documented in indicators such as high desired sex ratios at birth (Bongaarts, 2013) or distorted sex ratios of mortality as shown in Alkema et al. (2014) and chapter 6 of this thesis also show uptake of prenatal sex selection?

The current literature does not provide a specific model to predict and anticipate the future course of SRB trajectories. Two ways of potentially generating

forecasts for SRBs are presented in this thesis in parts I and II. Although the microsimulation model in part I is not explicitly presented here as a tool for projections, it can be extended for this purpose. As discussed in chapter 4, a number of issues would be helpful in expanding the applicability of the model to different contexts and as a generalised projection tool. Methods to modify the existing parameterisations of readiness, willingness and ability to better incorporate available data would be valuable extensions. For example, variations in the strength of son preference across a wider range of countries may not be adequately captured in ideal fertility preference measures of fertility surveys. Given limited data points about the timeline of ultrasound diffusion, data from web search as shown in chapter 4 might offer potential clues about this process that can be incorporated in the simulation model. However, as the results of chapter 4 indicate, these data may work better in some contexts (e.g areas with better internet diffusion and higher birth registration) than others.

This brings about a set of incumbent issues about how to manage uncertainty in simulation models. A number of sources of uncertainty are inherent in simulations models. These include uncertainty due to simulation stochasticity, due to limited understanding of model behaviour at outputs that are not run by the simulator, uncertainty about the input parameters in the simulation, as well as uncertainty due to model discrepancy since the simulation is simplification of the social process, which is likely significantly more complex in the real world (Hilton and Bijak, 2017). A number of approaches drawing on the Bayesian tradition have been suggested in order to deal with uncertainty analysis in simulation models – these include Bayesian melding (Poole and Raftery, 2000) and Gaussian process emulators (Oakley and O'Hagan, 2002). Moving forward, these approaches could be fruitfully combined with extended formulations of the RWA model, to generate SRB projections.

8.2.3 The Underpinnings of Excess Female Mortality

At the macro-level, chapter 6 in this thesis reported the presence of distorted sex ratios of mortality indicative of excess female mortality. In line with the literature, this notion of excess was informed by patterns of change in sex ratios of mortality that have been observed as mortality levels have declined across the world (Alkema et al., 2014; Sawyer, 2012; Tabutin and Willems, 1995; Hill and Upchurch, 1995). Implicit in this perspective is that countries that deviate from this global pattern of change in the sex ratios of mortality come about through some form of gender discrimination (see for example, Bongaarts and Guilmoto (2015)). This, however, may not necessarily be the case. Our understanding of the forces driving variations across countries in the sex ratios of mortality, as well as patterns over time, remain limited. Although changes in the cause of death composition with the shift from infections to congenital diseases over time have been proposed as the mechanism underlying increases in the sex ratios of infant mortality in the developed world (Drevenstedt et al., 2008), data on global cause of death patterns are often too poor to be able to disentangle the impact of the cause of death compositions on explaining variations in sex ratios in infant and child mortality across the world. Better availability of cause of death data that agree with available mortality estimates may be a useful source of data to exploit in order to better understand variations in sex ratios of infant and child mortality.

Similarly, a deeper examination of the pathways of patterns of disadvantage in mortality by sex are needed. In chapter 7, I highlighted how patterns of disadvantage by sibling composition exist for girls in contexts where SRB distortions exist as manifestations of son preference. This analysis can easily be extended to a wider geographical scope with available demographic data, and further research should seek to address factors that might shift these patterns of disadvantage and gender gaps in mortality in general. Chapter 7 found little role for prenatal sex selection – with the exception of India – in explaining changes in sex-differentials in

mortality. What other factors – ideational change driven by women's education, overall fertility decline, among others – might drive these changes? Assessing mechanisms that bring about reductions in gender inequalities in health and survival is an area with much potential for research. Furthermore, as small family sizes spread globally, do patterns of excess female mortality continue to reflect sex-selective allocation of resources such as immunisation or breastfeeding, as has been suggested in the literature on South Asia, or might indirect mechanisms of excess mortality through the fertility effects of son preference that results in girls being born into larger families be more salient? Distinguishing between these two effects remains an important area for research.

8.2.4 Computational Approaches in Demography

This thesis has presented examples of the use of computational approaches to demographic research. This is an exciting area for further research, both in terms of techniques (e.g agent-based or simulation techniques, online experiments) as well as data sources (e.g web and social media data). Sections of this thesis contribute a recently published volume that has attempted to consolidate and reinvigorate interest in individual-based simulation approaches in population studies (Kashyap and Villavicencio, 2017). In order to make simulation approaches more mainstream in demography, chapters in that volume suggest the use of streamlined protocols such as the Overview, Design, Details + Decisions (ODD+D), a verbal description of simulation models originally adopted in ecology, to the practice of simulation in demography (Groeneveld et al., 2017). Given different programming platforms and tools used by researchers, the ODD+D provides a common platform to understand the workings of simulation models.

Digital data offer promise for demographic research, but their limitations must also be understood and suitable approaches need to be developed to account for these. For example, as these data are not collected as surveys or censuses are,

these data suffer from issues such as lack of representativeness (Zagheni and Weber, 2015). Works such as Zagheni and Weber (2015) provide insights on how to correct for these issues. With respect to chapter 5 in this thesis, lower levels of internet penetration in low birth registration states, which tend to be poorer, might account for why Google search predictions perform less well in these settings. Developing a model that reasonably accounts for this variation to generate SRB predictions based on web data would be a valuable step moving forward.

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