Chapter 7
The Evolutionary Demography of Sex Ratios in Rural Bangladesh

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Abstract In this chapter, we use evolutionary models of sex ratio variation to examine offspring sex ratios in Matlab, Bangladesh, from the 1960s to 2010, during which time sex ratios have shown a decreasing male bias. Evolutionary models lead us to examine particular aspects of family ecology, yielding predictions both unique from and similar to those proposed in the demographic literature. We examine three evolutionary models—the costs of reproduction model, the Trivers–Willard hypothesis, and the local resource competition and enhancement models. Our results support both the Trivers–Willard and local resource competition/enhancement model, but results for the costs of reproduction model are weak. In general, we find that variables associated with higher wealth, status, and engagement in agriculture are linked to more male-biased offspring sex ratios, while higher fertility, older age at marriage, and higher women's education are associated with less male-biased sex ratios. We also examine how Bangladesh fits into the larger cultural area of South Asia known in the press and policy circles for its high sex ratios. We compare the correlates of sex ratio in Matlab to those in other parts of the region and discuss why sex ratios in Bangladesh are less male biased, despite shared cultural characteristics, such as son preference and dowry, which some argue "cause" high sex ratios in parts of India and Pakistan. We conclude with a discussion of the utility of evolutionary models and offer policy recommendations for the region.

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7.1   Introduction

Male-biased sex ratios and parental behaviors meant to manipulate child sex ratios raise controversial ethical questions and generate complicated cross-cultural debates on public policy, public health, and gender equity. Perhaps no part of the world is a better example of this dynamic than modern South Asia. This area is well known for its male-biased sex ratios, strong cultural norms of son preference, and various forms of discrimination against daughters. Less commonly recognized, however, is sex ratio diversity within South Asia itself—although many areas have strongly male-biased sex ratios, others are more balanced. Some of these regional differences are linked to social and economic distinctions, yet the causes of sex ratio variation on a regional scale are often difficult to ascertain.

Bangladesh is in some ways an anomaly. The country has a long history of cultural practices associated with male-biased sex ratios in India, Pakistan, and China, including patrilineal inheritance, patrilocal residence, a strongly male-biased labor force, relatively low levels of female education, rapid economic development and urbanization, and rising dowry costs (Arnold et al. 1996; Clark 2000; Das Gupta and Bhat 1997; Das Gupta et al. 2003; Echavarri and Ezcurra 2010; Edlund 1999; Guilmoto 2009; Hesketh and Xing 2006; Murthi et al. 1995). A sex ratio of 105 males to 100 females at birth is considered normal. In Bangladesh, the sex ratio at birth in 2011 was 104, a low (unbiased) number similar to regions of South Asia, such as Sri Lanka, Nepal, or Kerala State in India, and in stark contrast to some regions of India or Pakistan where sex ratios can be as high (male biased) as 120 (United Nations 2011; see Table 7.1). In fact, there has been a noticeable *decline* in sex ratios in rural Bangladesh in the past two decades, during a period when sex ratios in much of North India have been rising. Studies on sex ratio in Bangladesh are very limited, however. Although some statistics have been reported (e.g., International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDRB 2012b), they have not been explored in terms of patterns and correlations.

Clark (2000) used a family-level approach to explore son preference in India according to socioeconomic status (SES) and region. Otherwise, most sex ratio analyses published in the demographic literature take place at the population level, with comparisons made between states or countries (e.g., Guilmoto 2009; Miller 1989). Population measures of sex ratio give us aggregate measures across a large number of families during a particular time period and for a particular age group. While such aggregate statistics are useful in describing population trends, they can conceal differences between families and trends occurring within or across families over time. To fill this gap in the literature, we analyze sex ratio at the level of the family, testing the degree to which offspring sex ratios match predictions from the evolutionary literature. A similar approach has been used to study sex ratio variation in non-human animals, for instance in bird clutches (e.g., Krakow and Tkadlec 2001). Evolutionary approaches to sex ratios spotlight parental investment strategies in particular, asserting that when one sex of offspring out-earns the other, or costs more to raise, or when only children of one sex inherit or take care of parents

Table 7.1 Sex ratios in South and East Asia

Region	Sex ratio[a]	Age range	Years	Source
East Asia				
China	118	Birth	2010	Hudson 2011
	110.2	1–5 years	1990	Coale and Banister 1994
Tibet	97–107	Birth	2005	Li 2007
Hainan	122	Birth	2005	Li 2007
Shanghai	120	Birth	2005	Li 2007
Guangdong	138	Birth	2000	Li 2007
Korea	112.5	Birth	1990	Park and Cho 1995
	111.4	4 years	1990	Park and Cho 1995
Taiwan	109.1	Birth	1990	Park and Cho 1995
	106.6	4 years	1990	Park and Cho 1995
Japan	104.9	0–4 years	2000	Census of Japan 2005
	104.8	0–4 years	2005	Census of Japan 2005
South Asia				
India	108.6	Birth	2011	Census of India 2011
	109.4	0–6 years	2011	Census of India 2011
Punjab	118.2	0–6 years	2011	Census of India 2011
Haryana	120.5	0–6 years	2011	Census of India 2011
Kerala	104.3	0–6 years	2011	Census of India 2011
Chhattisgarh	103.7	0–6 years	2011	Census of India 2011
Meghalaya	103.1	0–6 years	2011	Census of India 2011
Pakistan	105	Birth	2010	CIA Factbook 2012
	106	0–14 years	2010	CIA Factbook 2012
Nepal	94	0–4 years	1971	Nepali National Population Census 2011
	104.9	0–4 years	2011	Nepali National Population Census 2011
Sri Lanka	104.3–105.2	Birth	1985–1988	Abeykoon 1995
	104	Birth & 0–15	2012	CIA Factbook 2012
Bangladesh	104	Birth	2011	CIA Factbook 2012
	103	0–14 years	2011	CIA Factbook 2012
	102	Birth	2010	ICDDRB Workbook 2012b
Matlab	103.4	0–4 & 5–9	2006–2010	ICDDRB Workbook 2012b

[a] Sex ratio is read as the number of boys per 100 girls. Other notations for sex ratio exist, including number of girls per 1,000 boys (commonly reported in India)

in old age, parents use this information to make strategic decisions to favor the more beneficial or less costly sex (Hrdy and Judge 1993).

Our aims in this chapter are twofold. First, we evaluate whether evolutionary models of sex ratio variation explain patterns of offspring sex ratio in Matlab, Bangladesh. Some predictions are similar to those proposed in the demographic literature, but some are unique. We then test our predictions to see (a) whether the relevant variables have the expected effect on sex ratio and (b) whether particular evolutionary models are more important than others in understanding offspring sex ratios. Second, we examine how the Bangladeshi case fits into the larger cultural

area of South Asia, known in the press and policy circles for its high sex ratios. We discuss which correlates of sex ratio are similar to those in other parts of South Asia and which are not, and why sex ratios in Bangladesh differ despite sharing many cultural characteristics, such as son preference and dowry, thought to "cause" high sex ratios in other parts of the subcontinent. We conclude with a discussion of the efficacy of evolutionary models and by offering several public policy recommendations for Bangladesh and the region as a whole.

7.1.1   Mechanisms of Sex Ratio Variation

Among humans, a "natural" sex ratio at birth has consistently been reported as 105 males to females, i.e., for every 100 females born, around 105 males are born (Coale 1991). Cross-culturally, a sex ratio that falls within the range of 104–107 is generally considered normal (Chahnazarian 1988). The sex ratio at birth (also known as the secondary sex ratio, the primary sex ratio being the sex ratio at conception) is determined in large part by two biological mechanisms: sex determination at conception and spontaneous abortion during gestation. There is some evidence that the mother's health and nutritional condition affect the sex of a fetus (Cameron 2004; Zhou 2007), as well as some evidence for sex-specific mortality in utero (Catalano et al. 2005; Navara 2010). These findings suggest that women in better health give birth to more boys than do women in poorer health, although the mechanisms that underlie the relationship are not well understood. Other factors, such as coital frequency (James 2009) and hormonal concentrations of parents at the time of conception (James 2012), may also affect sex ratio at birth. For example, James (2009) and others have argued that there are higher male sex ratios at birth during and after wars, an effect possibly driven by coital rates.

Several mechanisms are thought to be largely responsible for the biased sex ratios at birth or within the first years of life in many parts of Asia (Das Gupta and Shuzhuo 1999). Preferential female abortion has been reported in areas where son preference is high and technology is available to determine the child's sex before birth (Das Gupta and Bhat 1997; Echavarri and Ezcurra 2010; Hesketh and Xing 2006). Where such technology is not available, however, parents can bias the sex ratio of their offspring through intentional neglect of daughters leading to higher female mortality (Hesketh and Xing 2006; Miller 1989). Additionally, Park and Cho (1995) suggest that parents can affect the sex ratio of their offspring through differential contraceptive use, which may be especially important when family sizes are moderate and parents can use contraceptives to stop reproduction after the birth of a son. Although infanticide occurred in India (Dickemann 1979) and elsewhere in Asia in the past (Guilmoto 2009), and is often unreported (Das Gupta and Bhat 1997), it appears to be rare in recent years (Guilmoto 2009; Hesketh and Xing 2006; Park and Cho 1995), and thus is not likely to be a significant cause of contemporary sex ratio bias.

Sex ratio at birth is important for understanding biological differences between populations including population responses to stress and forms of sex ratio manipulation which occur before birth, such as sex-selective abortion. To better understand sex ratio manipulation of the type reported to be common in South Asia, however, sex ratios among older children more closely reflect sex ratio *after* any parental modifications have been made. For these reasons, we examine sex ratio among children surviving to age ten, the earliest age at which children begin to adopt adult roles including working outside the home, labor migration, and marriage, though most children do not experience these events until older ages. Many demographers investigate sex ratios among children aged 5 or older to study the impact of different types of sex ratio manipulation occurring after birth (e.g., Clark 2000; Das Gupta and Shuzhuo 1999; Miller 1989). Additionally, studying child sex ratios reflects an emphasis on comparative parental investment strategies in behavioral ecology and evolutionary demography.

7.1.2 Evolutionary Explanations

Typical explanations of biased sex ratios in the demographic literature focus on cultural constructs such as son preference or female empowerment, but these proximate explanations do not answer the question of *why* differences in parental investment or gender roles exist to begin with. Evolutionary approaches, in contrast, focus on ultimate explanations which attempt to understand the root cause of a phenomenon in terms of behavioral strategies meant to result in higher fitness. An evolutionary approach can connect proximate explanations to an overarching theoretical framework (e.g., Clarke and Low 2001). Evolutionary theories of sex ratio and sex-biased investment suggest reasons for why son preference may be so prevalent cross-culturally and the circumstances in which it is most likely to exist, as well as why empowered women have children with more equal sex ratios (Hrdy and Judge 1993).

Our work falls squarely into the field of evolutionary demography (e.g., Clarke and Low 2001), combining demographic data and research questions with evolutionary models and drawing on methods from both fields. Evolutionary theoretical models typically show how similar ecological circumstances give rise to predictable outcomes, allowing us to generalize about how an underlying process will play out in different contexts. In contrast, studies in public policy or demography typically examine many variables to identify those of interest in a specific context; they may or may not refer to an underlying theoretical framework. We argue that these approaches can be usefully combined by constructing and comparing models that include both evolutionary predictors and key contextual variables to gauge their relative importance.

7.1.3   Sex Ratio in South Asia

There is tremendous variability in sex ratios throughout East and South Asia, running counter to the popular media portrayal of uniformly high male bias. Here, we introduce the variation in and correlates of sex ratio in the region (Table 7.1).

In India, the sex ratio has been steadily increasing over the past 40 years. Even so, the nationwide sex ratio of 109.4 for ages 0–6 is still only moderately higher than the normal range of sex ratio variation (Chahnazarian 1988). In fact, it is not the nationwide average that has garnered significant attention, but the very high sex ratios in some states in northern India (Arnold et al. 1996; Clark 2000; Das Gupta 1987). In the state of Punjab, for instance, the sex ratio for ages 0–6 is currently 118, but has rarely dipped below 110 over the past 40 years. This represents the extreme end of a trend that incorporates many Indian states, thought to be the result of decreasing female child survival, a trend that runs counter to the increasing survival found in other parts of the country (Agnihotri 1995, 2000).

Son preference is a strong norm across South Asia and many see it as the catalyst behind high sex ratios in the region (Das Gupta and Bhat 1997; Das Gupta and Shuzhuo 1999; Echavarri and Ezcurra 2010; Miller 1981). In other parts of the world where son preference is strong, most notably China and Korea, biased sex ratios are also reported (Johansson and Nygren 1991; Park and Cho 1995). Park and Cho (1995) suggest that the bias in the sex ratio in modern Korea is due to the presence of son preference in a low-fertility society; families have fewer children than in the past, but their preference for sons remains high, leading to behaviors that bias the sex ratio in favor of males.

Both individual and group effects appear to impact son preference. Murthi et al. (1995) report that decreased income and increased education, especially among females, are related to decreased son preference, though the direction of causation is unclear (see also Clark 2000; Echavarri and Ezcarra 2010). Religion and caste are also potential correlates of son preference, especially in India (Clark 2000; Pande and Astone 2007). Hindus and Sikhs are found to have the highest son preference followed by Muslims and finally Christians, while low-status groups such as Scheduled Castes and Scheduled Tribes and people in North India also have higher-than-average son preference (Clark 2000).

Son preference also appears to be related to dowry (Arnold et al. 1996; Clark 2000; Das Gupta et al. 2003; Edlund 1999; Guilmoto 2009). Dowry, which is paid by the bride's family at the time of marriage, is often seen as a financial burden imposed on the family by daughters (Edlund 1999), who typically do not contribute significantly to the family income, especially in rural areas (Das Gupta et al. 2003). Sons, on the other hand, contribute to the family economy in the forms of income from wage labor and dowry paid by their wife's family (Mutharayappa 1997). Therefore, increases in dowry payments may result in increased son preference.

One of the primary proximate mechanisms impacting sex ratio in South Asia appears to be preferential female abortion, especially in places such as India, China, and Korea, where ultrasound technology is readily available (Echavarri and Ezcarra

2010; Das Gupta and Bhat 1997). When there is no access to prenatal sex detection technology, son preference may lead parents to focus instead on having an ideal number of sons, stopping only after the desired number of sons is achieved (Arnold et al. 2002; Clark 2000). Such a strategy becomes problematic, however, with preferences for smaller families (Das Gupta and Shuzhuo 1999; Murthi et al. 1995), and sex-specific neglect may be employed as a way to bias the sex ratio towards sons after birth (Das Gupta 1987; Miller 1981; Rosenzweig and Scultz 1982).

Many regions of South Asia have a sex ratio of 105 or lower (Table 7.1). Low sex ratios are most common in South and Northeast India, areas that are historically matrilineal, practice rice agriculture, and/or have large culturally distinct tribal populations. Sri Lanka and Nepal also have low sex ratios. Sri Lanka shares some cultural features with South India, but Nepal more closely resembles North India including strong traditions of patrilineality and patrilocality. Women in Sri Lanka have higher status than in other parts of South Asia, including higher literacy, education, life expectancy, and participation in economic activities (Abeykoon 1995). To a lesser extent, women in Nepal also have higher status than women in North India do.

Although sex-selective abortion is less common in Bangladesh than in India (Hesketh and Xing 2006), preferential female neglect through food distribution has been reported (Chen 1982; D'Souza and Chen 1980; Miller 1989). Chen (1982) has suggested that differences arise between India and Bangladesh because of the heterogeneity of the Indian population with respect to socioeconomic markers, such as ethnicity, religion, income, and modernization. Yet, while Bangladesh has less socioeconomic and cultural diversity than the much larger India, this does not explain why Bangladeshi sex ratios are similar to some parts of India but not others. Indian regions with low sex ratios, such as Kerala State and Northeast India, for instance, can be quite culturally and religiously diverse.

7.1.4   The Politics of Sex Ratios

In public policy circles, unbalanced sex ratios are usually seen in a negative light, as either a consequence or a cause of social problems. Much attention has been paid to discrimination against daughters through sex-biased abortion, infanticide, and sex-specific neglect, leading to higher female mortality, undernutrition, or morbidity (e.g., Chen 1982; Das Gupta and Shuzhuo 1999; Miller 1981). Also of concern are the social implications of large numbers of unmarried men, including the difficulties individuals and families face if sons are unable to find a marriage partner, have children, or take care of parents and family businesses (Hudson and den Boer 2004). Moreover, some argue that such pressures could lead to rising rates of domestic violence and social conflict (Hudson and den Boer 2004); yet, others have argued that the perspectives of policymakers do not necessarily follow from logically consistent models (Brooks 2012). Moreover, views of unbalanced sex ratios as a social problem can be seen as ethnocentric, since such perspectives often reflect the views of

Fig. 7.1 Women processing rice in Matlab. Both men and women work in the fields, but women are responsible for much of the post-harvest processing of crops in Bangladesh. (Photo courtesy of Mary K. Shenk)

policymakers in developed countries rather than the perspectives of local families facing difficult trade-offs.

7.1.5   Study Population

Matlab, Bangladesh, is a rural area located in Chandpur District. Villagers of Matlab traditionally practiced agriculture(Fig. 7.1), fishing, and small trading (Holman and O'Connor 2004; ICDDRB 2007). Over the past three decades, however, these practices have been changing in response to decreasing land ownership and increasing access to local, national, and international labor markets (Kabeer 2001; Nowak 1993). Bangladesh is also undergoing a demographic transition; between 1966 and 2010, total fertility rates in Matlab fell from 6.7 to 2.6 children per woman (Fig. 7.2). Conversely, life expectancy at birth rose from 53 to 69.3 years for men and from 51 to 73.2 years for women, due mainly to sharp decreases in infant and child mortality (ICDDRB 2007, 2012). There is evidence that in some parts of India, China, and Korea, declining fertility rates are associated with increasing son preference and thus higher sex ratios (Guilmoto 2009; Nie 2009; Sekher and Hatti 2010). This does not appear to be the case in rural Bangladesh, where recent evidence suggests that child gender preference may be shifting towards a higher valuation of daughters (Fraser 2011).

Fig. 7.2 Lower fertility in Matlab, Bangladesh. A family including mother (*left*), father (*right*), grandmother (*rear*), and two daughters. (Photo courtesy of Mary K. Shenk)

Agriculture in Matlab has decreased as a primary occupation, and villagers have increasingly adopted wage labor, largely in construction, transportation, and small businesses. Labor out-migration has also increased, with more men traveling to cities in Bangladesh or abroad to work as laborers, primarily in construction and maintenance, or as domestics (Afsar 2009; ICDDRB 2007; Nowak 1993). Although men who are labor migrants may not be physically present in the household, they usually remain financially and socially connected to their families, sending remittances home to their parents, wives, and children. Educational levels for both men and women are increasing (ICDDRB 2007), though for men, this is much more likely to pay off in the labor market, whereas for women, education is primarily expected to pay off in the marriage market and serves as a backup strategy in case the woman is widowed or divorced.

In rural Bangladesh, families are extended or nuclear and live in close proximity to other kin in a *bari* or patrilineal compound (Aziz 1979). Patrilocal residence and patrilineal inheritance are the norm, with sons staying with or near their parents and daughters marrying into more distant families. Matlab villagers traditionally paid bride-price (a payment from the groom's family to the bride's family at marriage), but now almost exclusively pay dowry (a payment from the bride's family to the groom or groom's family at marriage). This transition has taken place in the past several decades, possibly due to changes in Bangladeshi family law that requires marriage registration, or more generally to economic development, as in other regions of South Asia (Ambrus et al. 2010; Caldwell 2005). Dowries may serve as hedges against divorce, as well as a form of premortem inheritance for women (Ambrus et al. 2010; Esteve-Volart 2004). In wealthier families, daughters obtain higher levels of education and marry at older ages; their families often pay larger dowries to marry their daughters to higher-status grooms (Esteve-Volart 2004). Poorer families may marry daughters early to lower-status grooms in order to avoid burdensome dowry payments, which tend to increase with the daughter's age and perceived risks to her chastity (Caldwell 2005).

Son preference is traditional in South Asia (Das Gupta et al. 2003), including rural Bangladesh. Sons remain economically connected to and responsible for their birth families, including caring for younger siblings, elderly parents, and their own families after marriage. Sons generally bring in the dowry at marriage and may have religious obligations to parents, such as lighting their parents' funeral pyres among Hindus. Daughters, on the other hand, rarely work before marriage in rural Bangladesh. Any income they earn after marriage becomes part of the finances of their husband's family. These norms may be changing, however. Although daughters were always instrumental in helping take care of younger siblings, our qualitative interviews highlight the increasing importance of girls in helping their families, including their aging parents, after marriage. Help from daughters may be especially important if sons and daughters-in-laws are physically absent from the *bari* due to labor migration (Afsar 2009; Fraser 2011).

7.1.6 Evolutionary Models of Sex Ratio

In the past 40 years, both theoretical and empirical studies of human and non-human sex ratios have proliferated in evolutionary ecology (e.g., Cockburn et al. 2002; Kokko and Jennions 2008; Hardy 2002; Sieff 1990). Here, we describe several evolutionary models of sex ratios and the predictions we draw from them for our Matlab sample.

Costs of Reproduction Hypothesis Although Darwin knew that within a species, male and female offspring are typically produced in equal numbers (Darwin 1871), it took until the 1930s for Fisher (1930) to suggest a plausible evolutionary explanation for the phenomenon. Fisher reasoned that males and females should be produced in roughly equal numbers because, as population sex ratio drifts from equality, parents who produce the rarer sex will have higher fitness. Fisher further reasoned that when one sex is more costly to raise (in terms of time, energy, or resources), parents should increase production of the less costly sex such that expenditure on male and female offspring is equal.

Starting in utero, male neonates, and to a lesser degree male infants and children, are more vulnerable to mortality as well as morbidity early in life, especially when infectious diseases and malnutrition are common and modern medical care is limited (McMillen 1979; Waldron 1985). Taken on a per-offspring basis, males may be less costly than females simply because they are, on average, alive for a shorter amount of time. According to the equal expenditure hypothesis, this may explain the male-biased sex ratio at birth (Fisher 1930). This view leads to "Prediction 1: Higher-male neonatal mortality rates should be positively correlated with male-biased sex ratios at birth." We test this using the male neonatal mortality rates in Matlab, Bangladesh, when the woman was 18–20 years old.

Wells (2000) argues that greater intrinsic male vulnerability during gestation, infancy, and childhood could itself be a direct product of natural selection if male and female children offer different returns on parental investment. When environmental conditions are poor, the greater vulnerability of male infants makes them less likely

to survive or thrive in conditions that are unfavorable for male children, and those males who do survive will be the ones in better condition. Poor parental condition or poor local conditions should therefore lead to a more female-biased sex ratio among surviving children.

Moreover, despite greater male vulnerability, evidence suggests that for human mothers, producing a surviving male is more costly than producing a female (Mace and Sear 1997; Helle et al. 2002). Males require more caloric investment both in utero and during lactation and even appear to decrease maternal longevity in certain contexts (Helle and Lummaa 2013; Helle et al. 2002). Given such costs of reproduction, mothers are predicted to adjust their offspring sex ratios according to their own ability to bear the costs of producing sons (Gomendio et al. 1990; Myers 1978). Both a mother's current circumstances and the conditions she experienced during development are likely to be important. For example, Gibson and Mace (2003) found that Ethiopian mothers in good condition, specifically those with higher body mass indexes (BMIs) and upper-arm muscle mass, were more likely to have produced a son in their previous birth.

Thus, the framework of the costs of reproduction also leads to"Prediction 2: Offspring sex ratio will be negatively correlated with poor parental or local conditions, as parents find it more difficult to raise sons to adulthood." Specific predictor variables are whether the woman experienced food insecurity when she was herself a child, and the number of child deaths which occurred in the woman's marital bari during the first years of her marriage (excluding her own children).

Trivers–Willard Hypothesis Trivers and Willard (1973) suggest that in cases where parental investment has an impact on an offspring's future reproductive success, the sex of the offspring produced or reared should reflect parental condition (specifically maternal condition in most species). In species where sons in good condition (i.e., nutritional status, health, social status) are able to out-reproduce daughters in good condition, higher-quality mothers are predicted to be more likely to produce or rear sons. Conversely, in species where daughters in poor condition are able to out-reproduce sons in poor condition, lower-quality mothers are predicted to be more likely to produce or rear daughters. In humans, SES is an important attribute of parental condition and ability to invest in offspring, and although Trivers and Willard originally focused on the sex ratio at birth, they suggested that their model could also apply to postnatal investment. Trivers and Willard (1973) also recognized that paternal investment will reduce variance in male reproductive success relative to females. They argued that the model should still hold, however, if males in higher SES families out-reproduce their sisters, while females in low SES families out-reproduce their brothers.

The Trivers–Willard hypothesis has inspired significant research attention in humans and other primates (see Hrdy 2000, for an overview), with mixed results that have themselves inspired methodological critique (Brown 2001; Lazarus 2002; Towner and Luttbeg 2007). For example, Borgerhoff Mulder (1998) found that higher-status fathers produce more sons than lower-status fathers among the polygynous Kipsigis. And Cronk (2000) and Koziel and Ulijaszek (2001) found evidence

that Mukogodo mothers in Kenya and mothers in Poland, respectively, may engage in sex-biased breastfeeding patterns consistent with the Trivers–Willard hypothesis. In contrast, Keller et al. (2001) found no evidence that high-status families have more sons or low-status families have more daughters in contemporary USA and argued that resource allocation rather than sex ratio may be a more relevant measure of parental investment. Methodological issues in detecting Trivers–Willard effects are additionally complicated by potential publication biases (Festa-Bianchet 1966), small sample sizes (Brown and Silk 2002), and a focus on null hypothesis testing (Towner and Luttbeg 2007).

The Trivers–Willard hypothesis leads to "Prediction 3: Wealthier, higher-status families will have higher offspring sex ratios than poorer, lower-status families." Based on ethnographic data and observations, we use the variables household income, woman's education, husband's education, and whether the husband is a labor migrant as proxies for wealth and social status in Matlab.

Local resource enhancement and competition The local resource enhancement and Local Resource Competition models are two sides of the same evolutionary coin—one focusing on cooperation and the other on conflict. The local resource enhancement model proposes that if cooperation among offspring of one sex reduces the costs or increases the benefits of raising offspring, then the sex ratio should be biased towards the cooperating sex (Emlen et al. 1986; Flinn 1988; Turke 1988); local resource enhancement can also occur if offspring of one sex enhance the mating success of parents or siblings (Sieff 1990). The local resource competition model functions similarly; when there is competition among offspring of one sex for resources, the cost of raising offspring of that sex will increase, and parents should bias the sex ratio in favor of the less competitive, less costly sex (Clark 1978; Silk and Brown 2008).

A number of studies have shown the importance of philopatry on local resource competition in mammals, including primates (e.g., Johnson 1988; Silk et al. 1981; van Schaik et al. 1989). In humans, marital residence patterns do not necessarily determine the extent of within-sex competition (Borgerhoff Mulder 1998), but some support exists for local resource models. Borgerhoff Mulder (1998) and Mace (1996) found evidence of competition for resources among inheriting Kipsigis and Gabbra brothers. Quinlan et al. (2005) found that in Dominica, daughters cooperate with mothers in household tasks, freeing mothers to invest in younger children. Consistent with the local resource enhancement model, these mothers breastfeed daughters longer than sons (see also Bereczkei and Dunbar 2002). Hill and Kaplan (1988) suggest that one explanation for the high sex ratio among the Ache in lowland South America might be that sons are less costly to raise because they make a larger contribution to the family's food resources beginning around age of 16 (see also Smith and Smith 1994).

The local resource enhancement model leads to "Prediction 4: Families in which the labor of sons is able to contribute more directly to family resources should have higher sex ratios." Sons in South Asia are very important to kin in terms of income, social support, and care in old age. In particular, sex ratios should be high for sons in agricultural families where the labor of sons is the key means of generating an

income. Both land ownership and whether the family works in agriculture serve as measures of the likelihood of local resource enhancement. The local resource competition model leads to "Prediction 5: Daughters compete for resources when dowries are paid. Thus, families which expect to pay higher dowries should have higher sex ratios." Since not all daughters are married yet, we use the mother's dowry as a measure of dowry expectations.

7.2   Methods

7.2.1   Data

Results reported here are drawn from a detailed survey of 944 women aged 20–64, conducted in 2010 in Matlab, Bangladesh. The study area includes a population of approximately 250,000 people on whom detailed demographic data have been collected since 1966 as part of the Health and Demographic Surveillance System (HDSS) run by the ICDDRB, a public health and demographic research organization which has worked in the Matlab area for 50 years. Our sample was drawn randomly from a list of all women aged 20–64 living in the HDSS sample area. Even numbers of women were drawn from three 15-year age categories (20–34, 35–49, and 50–64) allowing for better representation of older women since rapid population growth in the Matlab area has resulted in larger cohorts of younger women. Our sample thus allows for 45 years of time depth.

Our survey covered topics including family demographics, education, marriage, occupation, income, migration, health, and risk. Surveys were conducted via interview in the woman's *bari* and took around 1 hour to complete. We focused our analyses on all women in our survey married for at least 5 years and for whom data were complete on our variables of interest ($N = 795$). Our sample excludes 63 unmarried women (all of whom are childless) and 73 women who have been married less than 5 years (many of whom are childless or only have one child). Only 12 women were excluded because of missing data in one or more variables; there were no clear patterns among these women likely to affect analyses. Summary statistics for all variables analyzed are shown in Table 7.2.

Our analyses focus on the children of women in the sample, simultaneously modeling two dependent variables: the number of boys and the number of girls born and who either survived to age 10 or were alive at the time of the survey in 2010. We count only birth children, excluding stepchildren and adoptees. In rural Bangladesh, it is rare for children to leave the household until they are teenagers so the majority of these children are living at home; fostering is not common except in cases of parental death. Although not all children had yet survived to age ten in 2010, we did not expect censoring to bias our results given that current fertility and mortality rates are comparatively low. Completed family sizes are currently two to three children (in 2010, the average total fertility rate (TFR) was 2.6; ICDDRB 2012a). Based on 2010 mortality rates for children aged 0–1, 1–4, and 5–9 in the

Table 7.2 Summary statistics for women in our Matlab sample

Variable	N	Mean	Standard deviation	Median	Range
Dependent variables					
Number of surviving sons	795	1.9	1.26	2	0–6
Number of surviving daughters	795	1.7	1.26	2	0–7
Continuous variables					
Woman's age at marriage (years)	795	16.2	2.93	16	11–33
Woman's age (years)	795	43.7	11.26	44	21 to 67
Household income (Taka per year, logged)	795	11.1	1.05	11.2	6.7–14.9
Husband's education (years)	795	4.8	4.43	5	0–16
Woman's education (years)	795	3.6	3.69	3	0–16
Value of woman's wedding gifts (logged)	795	4.9	5.07	0	0–13.3
Child deaths in marital bari (number)	795	1.6	1.87	1	0–15
Male neonatal mortality rate (deaths per 1,000)	795	62.4	17.8	63.5	20.7–95.7
Categorical variables					
Husband's location			Woman's fertility		
1 = Bangladesh	706		1 = low (4 births or less)	517	
2 = Abroad	89		2 = high (5 or more births)	278	
Family engaged in agriculture			Whether woman lost a child		
0 = no	407		0 = no	581	
1 = yes	388		1 = yes	214	
Family owns land			Food insecurity		
0 = no	204		1 = always had enough food	520	
1 = yes	591		2 = did not always have enough food	275	

Matlab area (ICDDRB 2012a), along with the ages of the children 9 and under included in our dataset, we estimated that at most only 9.5 of the children included in our analyses might die by age 9. Moreover, for these deaths to affect our overall results, there would need to be enough bias among the dead children to change the results for the full sample of 2,853 children.

The predictor variables used in this chapter are listed in Table 7.3. Age, age at marriage, and whether the woman had high or low fertility are considered control variables and are included in all models, including a base model with no other variables. The other predictor variables are related to the evolutionary models being tested (see above). Most predictor variables are from the time before the couple had children—this means that their effects can more plausibly be interpreted as causes of sex ratio rather than simply correlates of it.

Table 7.3 Bivariate relationships between offspring sex ratios and predictor variables

Variable	Levels	Surviving sons	Surviving daughters	Sex ratio (in subset)
Full sample		1,487	1,366	108.9
Woman's age at marriage	Under 15	690	604	114.2
	15–17	540	489	110.4
	18 and over	257	273	94.1
Woman's age	Under 40	358	356	100.6
	40–49	416	398	104.5
	50 and over	713	612	116.5
Woman's fertility	Low	739	642	115.1
	High	748	724	103.3
Household income	Low	444	462	96.1
	Medium	518	462	112.1
	High	525	442	118.8
Husband's education (years)	0	527	502	105.0
	1–5	445	388	114.7
	6 or more	515	476	108.2
Husband's location	Bangladesh	1,366	1276	107.1
	Abroad	121	90	134.4
Woman's education (years)	0	551	446	124.5
	1–5	601	579	103.8
	6 or more	333	345	96.5
Food insecurity	No	959	869	110.4
	Yes	528	497	106.2
Family engaged in agriculture	No	650	630	103.2
	Yes	837	736	113.7
Value of woman's wedding gifts	None	842	786	107.1
	<10.2	361	346	104.3
	≥10.2	284	234	121.4
Child deaths in marital bari	0	405	418	96.9
	1 or 2	640	574	111.5
	3 or more	442	374	118.2
Male neonatal mortality rate	Low	326	306	106.5
	Medium	481	469	102.6
	High	680	591	115.1
Whether woman lost a child	No	1,029	922	111.6
	Yes (1 or more)	458	444	103.2

Some women in our sample had likely not yet completed their fertility in 2010. To deal with this, we controlled both age and age at marriage in all analyses. We also removed unmarried women and newlyweds from the sample, excluding the women most likely to be below their completed fertility. Given that completed family sizes are currently two to three children (in 2010, the average TFR was 2.6; ICD-DRB 2012a), and that most women marry in their late teens or early twenties and have children soon afterwards, we calculated that likely around 80% of the women in our sample have completed fertility.

   All data were collected in accordance with human subjects research protocols approved by the institutional review boards at both the University of Missouri and ICDDRB. All research participants gave informed consent prior to data collection.

7.2.2 Analysis

Sex ratios within sibships or litters are sometimes analyzed as proportions, but this approach is problematic (Warton et al. 2011), as having 100 % sons means something very different for a woman with two children than a woman with six. Instead, we use generalized linear modeling (GLM) based on a binomial probability distribution (Wilson and Hardy 2002; Crawley 2005). Our dependent variable, which we refer to as offspring sex ratio, is a pair of values for each woman: number of surviving sons and number of surviving daughters, allowing us to model sex ratio in a manner which simultaneously accounts for the number of children. We identified 14 independent variables to evaluate as covariates in our model. All analyses were completed using R Development Core Team (2012) and the multi-model inference (*MuMIn*) package (Barton 2013).

   We use an information-theoretic approach (Burnham and Anderson 2002) to compare the evidence for alternative models and evaluate the importance of the independent variables in explaining sex ratio variation across women. This type of approach centers on the likelihood of each model given the data rather than null hypothesis testing (see Towner and Luttbeg 2007, for a review, with examples from sex ratio studies; see also Richards et al. 2011). Model comparison relies on Akaike information criterion (AIC) or variations thereof. For a given model, AIC $=-2\log(L)+2K$, where L is the likelihood of the model given the data, and K is the number of parameters in the model. In this analysis, we use a variation known as quasi Akaike information criterion (QAIC), which adjusts for overdispersion in the data (when the values of the dependent variable are non-independent; Richards 2008). We find a mild degree of overdispersion in our data ($\hat{c} = 1.2$).

   Our full model contains 14 covariates (including the three control variables in the base model). All possible subsets of this full model were constructed to calculate each model's QAIC value. Independent variables were assessed based on the number of top models in which they appear, as well as by the weight of those models, with the weight being a measure of the likelihood of that model among those being compared. For each variable, importance values are calculated as the sum of the weights of the models in which that variable appears (Table 7.3). Although a single best model (the model with the lowest QAIC) results from an exhaustive search, a number of models often have similar weights. We therefore used model averaging to construct a model that incorporated information from multiple top models. We followed the recommendations of Richards (2008) in estimating the averaged model, using all models with a $\Delta \leq 6$, where Δ is the difference between the model's QAIC value and the lowest QAIC value. We also filtered out all models that were more complex versions of a model with a lower QAIC value, with a further restriction that the control variables were retained in each model.
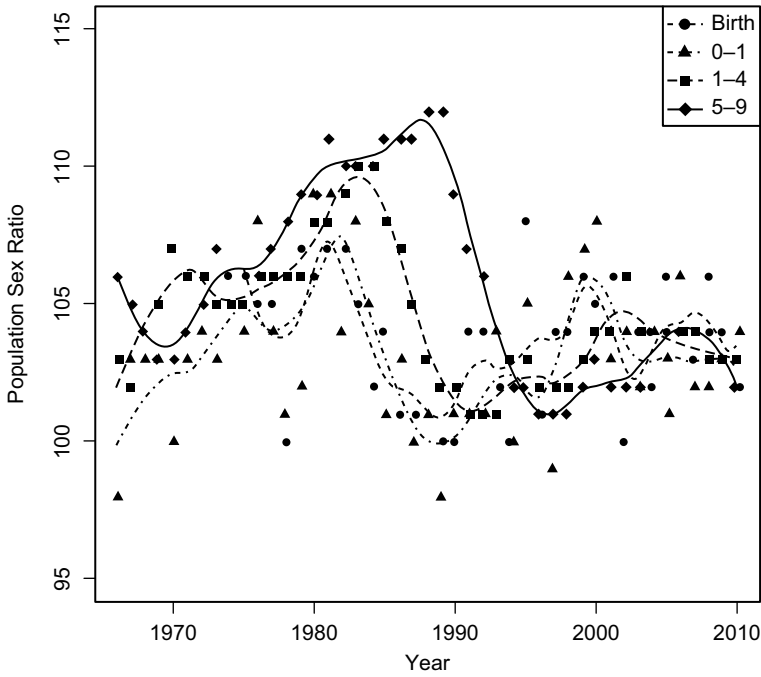
Fig. 7.3 Population level sex ratios for Matlab from 1966–2010. Points show the sex ratio for a given age range in a given year. Lines show the change in the sex ratio of four age categories (birth, 0–1, 1–4, and 5–9) over time. Lines were constructed through loess regression using a span of 0.25. The line for the sex ratio at birth begins in 1974 because birth data were not gathered before that. The trends include a sex ratio near 105 at the beginning of the study period, a spike in sex ratio towards the middle of the study period, and a return to sex ratios around 103 in recent years

7.3   Results

7.3.1   Sex Ratio Trends

Figure 7.3 shows sex ratios for the Matlab population from 1966 to 2010 for four age groups: birth, 0–1, 1–4, and 5–9 (ICDDRB 1981; ICDDRB Workbook 2012). Curves are plotted using loess regression with a span of 0.25. Matlab sex ratios began at around 105 in the early years of the sample, then rose in the late 1970s and 1980s to a high near 112 for ages 5–9, then dropped close to 100 around 1990, before slowly rising again to around 103. Cohort patterns can be viewed by looking first at the sex ratios at birth and 0–1, then following the trends for sex ratio at ages 1–4 and then 5–9 a few years later. A cohort effect can be seen between the mid-1970s and early 1990s. Sex ratios at older ages (0–1, then 1–4, then 5–9) are increasingly higher, suggesting greater female than male mortality at young ages in this period. These effects disappear in the mid-1990s, replaced by relatively similar sex ratios in different age groups and cohorts.

In addition, several patterns seen in Fig. 7.3 may be related to historical events. The Bangladesh Liberation War in 1971 was attended by widespread food shortages, social unrest, and mass killings which spread from the city to village areas (Nowak 1993). During 1971–1973, sex ratios in the 0–1- and especially the 1–4-year-old cohorts increased. Shortly thereafter, a 1974–1975 flood and devastating famine may have contributed to rising sex ratios in the 0–1 and 1–4 cohorts. Peak sex ratios in the early 1980s may be related to a major shigellosis epidemic in 1984 which had strong mortality effects on children aged 0–1 and especially 1–4. After this, sex ratios gradually fell, though they rose again slightly after a 1991 cholera epidemic before leveling off.

These data suggest that high mortality events in the 1970s and 1980s may have contributed to high sex ratios through excess female child mortality. This runs counter to the costs of reproduction model, from which we would expect excess male mortality in conditions of stress. It is possible that the effects of mortality events may not have been profound enough to affect the sex ratio at birth. Moreover, the higher rates of male survival during this period suggest intentional parental protection of sons or neglect of daughters, particularly during childhood, a finding consistent with reports of son preference in Bangladesh and the region (Clark 2000; Das Gupta et al. 2003). Despite additional mortality events, the unbiased sex ratio in recent years shows smaller sex ratio perturbations, possibly due to better medical care.

For the women in our survey, Fig. 7.4 shows the average number and sex ratio of surviving children grouped according to the year each woman was 18, the median age at first birth in our sample. To smooth out sampling variation and focus attention on women who are likely to have completed fertility, we show a running average (the year the woman was 18 ± 3 years) and limit the figure to women who were 18 or older in 2000. Between 1965 and 2000, the sex ratio among surviving children declined from about 125 to 100, although fluctuations were visible. Many older women in the early part of the sample have lost children, and many of those lost children were female, consistent with a pattern of son preference in nutrition and/or medical care. By the later part of the sample, however, sex ratios became lower and more stable, likely reflecting reductions in mortality due to better medical care and reduced son preference.

The correlated declines in sex ratio and fertility in our sample contrast with the increasing male bias found in parts of India and China during fertility transition (Guilmoto 2009; Nie 2009; Sekher and Hatti 2010). Also, although a sex ratio of 100 is low by global standards, it may reflect an emerging norm that favors two children, specifically one son and one daughter (Fraser 2011). And although sex ratios have fallen at the same time as the number of surviving children, we find that when controlling for age, women with four or fewer children had significantly higher sex ratios than women with five or more children, controlling for age (Tables 7.4 and 7.5). This pattern is replicated in every 5-year cohort between 1966 and 2010.
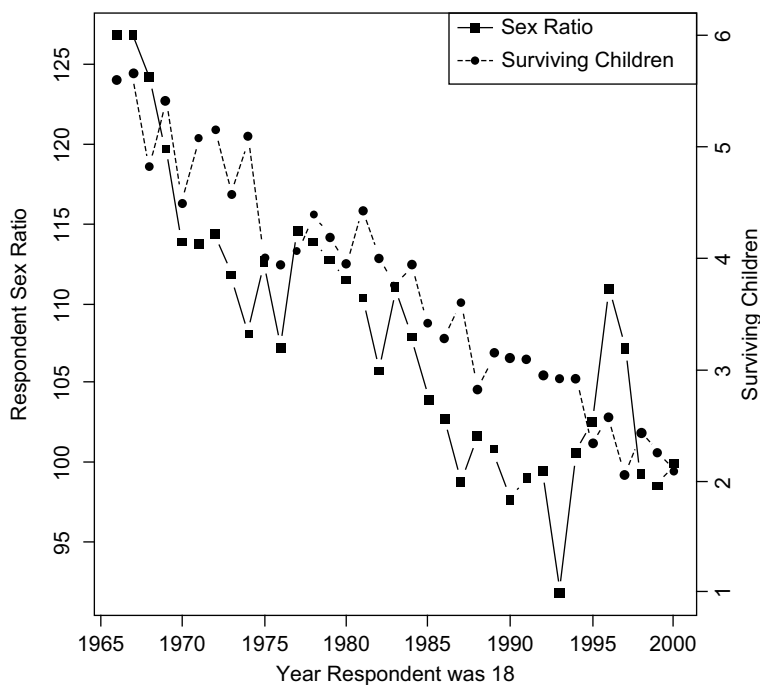
Fig. 7.4 Sample sex ratio and average number of surviving children by time. The x-axis groups women born in the same year and displays the year they were 18 years old (the average age of first birth). The left y-axis plots the sex ratio in our survey sample (*solid line*). The right y-axis plots the average number of children surviving to age 10 in our survey sample (*dashed line*). The figure suggests that sex ratios within our sample have become increasingly less male biased at the same time as fertility per woman has declined

7.3.2 Offspring Sex Ratios

Table 7.3 gives the sample sex ratios according to each predictor variable, with continuous variables turned into categorical variables for summary purposes only. Many of these cross-tabulations indicate meaningful sex ratio variation in the sample and some appear to match theoretical predictions. Table 7.4 summarizes the multi-model inference of offspring sex ratio using all variables. Of the 14 variables analyzed, a dummy variable for high fertility (five or more children), woman's age at marriage, and household income emerge as strong predictors, seen in the number of times each appears in the top 100 models, as well as their calculated importance values. The next six variables (woman's age, engagement of the family in agriculture, value of wedding gifts, woman's years of education, the husband's location, and the number of child deaths in the woman's marital *bari*) have meaningful explanatory power in at least some number of the models, while the remaining five variables (including male neonatal mortality rate, husband's education, food

Table 7.4 Multi-model inference: summary for full set of predictor variables

Variable[a]	Sign[b]	N in top 100 (no filter)	Importance ($\Delta_i \leq 6$, filtered)
Whether woman had high fertility (B)	−	100	1.00
Woman's age at marriage (B)	−	98	0.81
Household income (TW)	+	97	0.78
Whether family engaged in agriculture (LR)	+	80	0.61
Woman's age (B)	+	67	0.69
Value of woman's wedding gifts (LR)	+	66	0.38
Woman's years of education (TW)	−	62	0.42
Husband's location (TW)	+	52	0.43
Number of child deaths in marital bari (C)	+	49	0.32
Male neonatal mortality rate when woman age 18 (C)[c]		17	0.10
Husband's years of education (TW)[c]		14	<0.01
Whether woman experienced food insecurity (C)[c]		8	0
Whether family owns land (LR)[c]		4	0
Whether woman lost a child (C)[c]		3	0

[a] B=base (control) variable; TW=Trivers–Willard model; LR=Local Resource Enhancement/Competition model; C=Costs of Reproduction

[b] Refers to the sign of the variable's model coefficient, with positive values correlating with higher probability of surviving sons as the variable value increases, and vice versa

[c] Does not appear in the averaged model (Table 7.5), so no meaningful coefficient sign

insecurity, whether the family owns land, and whether the woman has lost a child) garner little to no importance among the filtered competing models.

Table 7.5 shows the averaged model resulting from our model selection and multi-model inference approach. In running diagnostics on the averaged model, we find that the predicted number of sons for each woman is strongly correlated with her actual number of sons (adjusted $R^2 = 0.463$, $p < 0.001$) with the caveat that the binomial distribution itself typically explains a large portion of the variance in sex ratio studies. All three of our control variables have significant effects on offspring sex ratio: older women have more sons, women who married at older ages have fewer sons, and women with five or more surviving children have fewer sons. Although we do not include a cohort variable, we have examined cohort effects in our analysis and they did not add any additional explanatory power. Temporal variation and secular trends are much better explained by the three control variables used here. While we use these variables as controls, they are also interesting in their own

Table 7.5 Model averaging of sex ratio predictor variables

Variable[a,b]	Estimate[c]	Adjusted SE	z value	p value
Intercept	−0.561	0.665	0.84	0.399
Woman's age at marriage (B)	−0.038	0.016	2.36	0.018
Woman's age (B)	0.011	0.005	2.15	0.037
Whether woman had high fertility (B)	−0.312	0.094	3.30	0.001
Household income (TW)	0.093	0.040	2.32	0.020
Husband's location (TW)	0.281	0.161	1.74	0.082
Woman's years of education (TW)	−0.023	0.014	1.69	0.092
Whether family engaged in agriculture (LR)	0.153	0.080	1.90	0.057
Value of woman's wedding gifts (LR)	0.015	0.008	1.82	0.069
Number of child deaths in marital bari (C)	0.034	0.021	1.67	0.095

[a] Variables are listed in order of model they are associated with
[b] B=base (control) variable; TW=Trivers–Willard model; LR=Local Resource Enhancement/ Competition model; C=Costs of Reproduction
[c] + sign means boys more likely, − sign means girls more likely

right. Older women had offspring at a time when both fertility and sex ratios were high, likely underlying the positive association of maternal age and sex ratio. The negative relationship between sex ratio and age at marriage may be related to the fact that in the earlier years of our sample age at marriage was low and sex ratios high, while in recent years later marriage and lower sex ratios became more common. The fact that this relationship exists despite a control for age, however, is also consistent with a life history perspective, namely that women who marry later—and thus have more limited opportunities to reproduce—will be less likely to manipulate the sex ratios of their offspring. Finally, the relationship between high fertility and low sex ratios suggests that couples may either have a larger number of children in pursuit of a certain number of sons or that parents who have sons initially limit overall fertility to focus on investment in those sons.

Several variables derive from the Trivers–Willard model. As predicted, household income has a strong positive effect on offspring sex ratio, suggesting that wealthier families have more sons. The husband's labor migration abroad also has a positive effect on sex ratio, perhaps because having a son or husband working abroad is a strong index of wealth and a local status symbol. Unlike other status measures, woman's education has a negative effect on sex ratio. Controls for other variables suggest that this is not simply due to her age, age at marriage, or wealth. While the effect of woman's education is not consistent with a straightforward interpretation of the Trivers–Willard model, it is consistent with a cost–benefit approach to life history in which higher education of mothers may be associated with higher expected payoffs to investment in daughters (Kaplan and Lancaster 2000).

Families engaged in agriculture are more likely to have sons, whose labor is highly valued, consistent with the local resource enhancement model. The value of the wedding gifts given for the woman's marriage also increases with sex ratio. This variable is both a measure of her family's wealth and a metric of the importance

Table 7.6. Model comparison

	Narrow				Broad			
Model[a]	K[b]	QAIC[b]	Δ_i[b]	w_i[b]	K	QAIC	Δ_i	w_i
Base model	4	1678.9	2.8	0.13	4	1678.9	4.4	00.5
Trivers–Willard	6	1676.1	0	0.52	7	1675.8	1.3	0.24
Local resource enhancement/ competition	5	1678.6	2.5	0.15	7	1674.5	0	0.46
Costs of reproduction	5	1678.0	1.9	0.20	7	1675.8	1.3	0.24

[a] The values shown are for the model within each class that results in the lowest QAIC
[b] "K" refers to the number of fitted parameters for each model; "QAIC" refers to information criterion for the best submodel in the model class; "Δ_i" refers to the change in "QAIC" between the lowest value and the model of interest; "w_i" refers to the Akaike weight

of dowry within the study area. Higher wealth and larger dowries are predicted to bias sex ratios towards sons; thus, this finding is consistent with both the Trivers–Willard and local resource competition models. Judging which variables are better included in Trivers–Willard versus local resource models is not always obvious. Any variable attributed to local resource competition or enhancement could be an indicator for Trivers–Willard, if transmitted across generations, and any variable attributed to Trivers–Willard could be a local resource indicator, if it needed to be shared between offspring of the same sex. We return to this concern into account in Table 7.6.

Finally, one variable from the costs of reproduction model appears in Table 7.5; the other variables modeled did not have sufficient importance to be retained (see Table 7.4). The number of child deaths in the woman's marital *bari* (an indicator of levels of risk and mortality in the woman's local environment) is correlated with *more* male-biased sex ratios, not less, and thus does not support prediction 2. On the other hand, one could argue that this effect is consistent with Fisher's (1930) prediction, also discussed in costs of reproduction, that when sons are more vulnerable to mortality than daughters, they should be on average cheaper to produce, potentially leading to male-biased sex ratios. This effect is, however, quite difficult to interpret for the Matlab population. While male neonatal mortality is higher than female neonatal mortality in Matlab (ICDDRB 2012b), possibly related to greater male vulnerability, infant and childhood mortality rates are more often female biased (ICDDRB 2012b). This is consistent with reports of higher female mortality in South Asia and may indicate son-biased investment during childhood (e.g., Miller 1981). Thus, in our sample, the positive relationship between local mortality and sex ratio may be driven not by biased sex ratios at birth, but rather by higher levels of child mortality in the past when son preference norms were stronger and access to medical care much more limited.

Table 7.6 shows a model comparison of the Trivers–Willard hypothesis, the local resource enhancement/competition model, and the costs of reproduction model. Assigning predictors is complicated, however, since some predictors can plausibly belong to more than one model. Therefore, a narrower and a broader version

of each model is compared—the narrower version containing only those variables most closely related to the model with overlap only in the base (control) variables, while the broader version contains a larger number of potentially related variables, some of which overlap between models. All models include the variables woman's age, age at marriage, and fertility level as controls, with a base model containing only these three variables included in the comparison.

Models are compared by beginning with a set of variables (either narrow or broad), then reducing each to its most parsimonious version. These parsimonious versions are then compared using Akaike weights. The narrow version of the costs of reproduction model includes child deaths in the marital *bari,* male neonatal mortality, whether the woman has lost a child, and food insecurity; the broad version adds household income as a measure of the woman's access to resources and thus ability to invest, the value of the woman's wedding gifts as a measure of the costs faced by daughters, and woman and husband's education as an indication of their expectations about the costs of educating daughters and sons. The narrow version of the Trivers–Willard model includes household income, husband's location, woman's education, and husband's education; the broad version adds two less direct measures of family status: whether the family owns land and the value of the woman's wedding gifts. Lastly, the narrow version of the local resource model includes family involvement in agriculture, the value of the woman's wedding gifts, and whether the family owns land; the broad version adds household income as a more general measure of the potential for competition among siblings.

The Trivers–Willard model has the highest Akaike weight and appears to be the model with the most explanatory power in the narrow model comparison, but the local resource Model comes out ahead in the broad model comparison, where broad versions of the Trivers–Willard and costs of reproduction models are exactly the same. Yet, in both cases, weight is shared among several models, suggesting that no single model has a clear advantage in terms of explaining variation in offspring sex ratios in Matlab, but rather that several types of causal explanation may be interacting. Given that this is observational rather than experimental data, it is hard to distinguish between models, and more than one model may contribute to the efficacy of a particular variable. A good example of this is the strong relationship between household income and higher sex ratios. There are many reasons why income could be so important: (a) Wealthier families/women are more able to bear the high costs of producing sons and raising them to maturity (costs of reproduction), or (b) higher-status families are more motivated to raise sons because of their potential to produce higher numbers of grandchildren (Trivers–Willard), (c) in rural areas, wealthier families are more likely to own land and need help from sons to make that land productive (local resource enhancement), or (d) that all three of these factors may be acting simultaneously.

The overall best model includes the control variables plus household income, respondent's education, husband's location, whether the family is engaged in agriculture, and the cost of gifts in the woman's marriage. This suggests that it is likely an interaction between the Trivers–Willard and local resource enhancement/competition models that may be most important in shaping offspring sex ratios in Matlab,

Bangladesh. In contrast, as seen in Tables 7.4 and 7.5, most of the predictors meant to represent the costs of reproduction have very low importance and are dropped from the model, while the model that remains, child deaths in the marital *bari,* has a somewhat ambiguous interpretation. This could either mean that the model is not particularly important in the Bangladeshi context or that the variables we used to test it were not ideal.

7.4   Discussion

Child sex ratios in Matlab have declined from around 112 in the late 1980s to the current low rate of 103. A sex ratio of 112 is a bit higher than the 2011 national average for India, where sex ratios are increasing and some states have child sex ratios as high as 120. In contrast, the current Matlab sex ratio resembles regions like Kerala or Meghalaya states in India, Nepal, and Sri Lanka, which have long histories of low sex ratios. Bangladesh is therefore not just an anomaly because its current sex ratios are low but because it has recently undergone a relatively substantial *decline* in sex ratio—counter to the trends in much of the rest of the subcontinent. The national average child sex ratio for Bangladesh is 104, suggesting that our findings from Matlab are relevant to other parts of the country as well. And given its proximity to the capital city of Dhaka, Matlab is a leading rural region for other trends, such as increased labor market engagement, reduction in the agricultural workforce, and labor migration to urban areas.

Although son preference is treated by demographers as a causal variable, evolutionary demographers view it as a proximate mechanism. In Bangladesh, son preference may derive from the effects of local resource enhancement on agricultural families where sons are needed to work the land to make the family prosperous. Local resource competition between daughters related to dowry might also promote son preference, though this is unlikely to be a strong factor in Matlab, since dowry was less common during the period when Matlab sex ratios were at their highest and became more common during the past 15–20 years as sex ratios have been falling. Son preference may also result from socio-ecological circumstances that make it very important for parents to have at least one son to help earn for the family and support them in their old age.

Our results also suggest two opposing effects with respect to mortality. Male neonatal mortality rates are almost uniformly higher than female neonatal mortality rates in Matlab from 1966 to 2010, the years for which we have data (ICDDRB ICDDRB 2012b), suggesting that there is excess male mortality shortly after birth which could be related to higher costs of reproduction of sons and/or higher male vulnerability. Two pieces of evidence, however, suggest that it is excess female mortality which is the key mechanism driving higher child sex ratios in some periods. First, in 1975, during the height of one of the worst famines in recent history which produced very high rates of infant and child mortality, the male infant mortality rate was 177.0 per 1,000, while the female infant mortality rate was 203.5 per

1,000; this was during a year when the male neonatal mortality rate was 79.3 versus a female neonatal mortality rate of 76.7, suggesting that the difference occurred well after birth. In contrast, once conditions improved 2 years later, male infant mortality was 112.2, while female mortality was 113.4 (ICDDRB 2012b). Thus, in times of very high mortality, daughters suffered more than sons, while at baseline, there was little difference. Another piece of evidence comes from preliminary data on the causes of death among children in our sample. For a subsample of children for whom we could find cause of death data, there were 275 deaths among 1,205 children. The sex ratio among children who died from 0 to 1 year was 129.2, while the sex ratio among children who died from 1 to 10 was 74.6, a significant difference ($X^2 = 4.38$, $p = 0.04$, df $= 1$, $n = 275$). Male vulnerability could be at work in the high sex ratio among infant deaths, while the strong female bias among child deaths suggests that sons were favored in access to food or health care.

7.4.1   The Value of Evolutionary Demography

What value do evolutionary models add over other kinds of demographic models in predicting and understanding sex ratios? Our results suggest that (a) in some cases, evolutionary models produce unique predictions and predictors not found in other literature and (b) in other cases, evolutionary models yield similar predictions but tie them to a broader theoretical framework capable of yielding ultimate-level explanations. For example, the relationship between wealth and sex ratio as described in the Trivers–Willard model is not often emphasized in the non-evolutionary literature on sex ratio per se, which generally treats income/wealth as a control rather than a causal variable. Another example is the relationship between agriculture and sex ratio. Though the shift away from agriculture may be discussed in non-evolutionary approaches, predictions drawn from an evolutionary understanding of local resource enhancement do not have a direct equivalent in the non-evolutionary literature. Given that these are two of the strongest predictors of sex ratio in our model, ignoring them could lead to significant theoretical and practical oversights.

Another example of the added value of an evolutionary perspective is in the interpretation of the effect of women's education. Demographers tend to argue that women's education is a measure of female autonomy, related to women's influence on decision making, as well as an index of women's status more generally (e.g., Anderson and Eswaran 2009). An evolutionary perspective leads to a related but more precise interpretation. More educated women grew up with higher levels of parental investment themselves, suggesting an environment in which there are tangible returns to educational investment in women as well as men. Women (and their husbands) with such characteristics may perceive similar returns to investing in daughters and thus invest more equally in children of both sexes, reducing the offspring sex ratio (Hrdy and Judge 1993). Although some economic demographers (e.g., Psacharopoulos and Patrinos 2002) have examined sex-biased educational investment in terms of the marginal benefits of educating sons versus daughters, these analyses are not couched in terms of the broader, ultimate context provided by evolutionary theory.

7.4.2 Why is Bangladesh Different?

Bangladesh is culturally and economically similar to many other parts of South Asia, especially states in North India with high sex ratios. Shared cultural practices include patrilineal descent and inheritance, patrilocal residence, a strongly male-biased labor force, relatively low levels of female education, rapid economic development and urbanization, and rising dowry costs (e.g., Brooks 2012; Das Gupta and Bhat 1997; Echávarri and Ezcarra 2010; Hesketh and Xing 2006; Murthi et al. 1995; Arnold et al. 1998; Clark 2000; Das Gupta et al. 2003; Edlund 1999; Guilmoto 2009). Consequently, the low sex ratios in Bangladesh are somewhat puzzling.

There are several possible explanations for this phenomenon. It could be that shared cultural or economic circumstances are less intense in Matlab than elsewhere, i.e., incomes are lower or more equal, there is less variation in education, dowries are lower, or son preference is weaker, suggesting that the sex ratio in Bangladesh could rise with changes in these indicators. It could also be that other countervailing forces are strong enough to keep sex ratios low. Rising age at marriage, increasing women's education, and the shift away from agriculture as an occupation might be enough to counteract the effects of rising incomes and increasing international labor migration. It is also likely that wider access to medical care through ICDDRB, other nongovernmental organizations, the government of Bangladesh, and private practice have been instrumental in reducing mortality rates and thus sex ratio bias, in Matlab. Better health care has co-existed with rising sex ratios in other parts of South Asia, however, so better health care alone is unlikely to explain the low sex ratios in Matlab.

Dowry is another practice frequently cited in connection with sex ratios in South Asia. The variable gifts given at the woman's wedding show the predicted effect, though it is a somewhat a weaker predictor of sex ratio than several other variables. This may be because we are using the mother's dowry as a guide to how much parents may expect to pay for their daughters, or because adoption of the custom of dowry is relatively recent in rural Bangladesh, or because dowries are low compared to other regions, meaning that the motivation for sex ratio manipulation due to dowry remains limited. Although dowries may be higher in some parts of North India with high sex ratios, the practice of dowry is nearly ubiquitous in modern South Asia. High dowries are also found in regions without biased sex ratios, such as the state of Andhra Pradesh in India, where the 2011 sex ratio for children 0–6 was just 106.0 (Census India 2011). Alternatively, it may be that high dowries and marriage costs are not direct drivers of sex ratio decisions per se but are correlated with more relevant social features, such as rising incomes due to rapid economic development, limitations on women's work and mobility, or strong patriarchal social norms. The social correlates and consequences of dowry are complex, and several authors have critiqued the idea of a direct causal link between dowry and various kinds of discrimination against women (Shenk 2007; Van Willigen and Channa 1991).

Bangladesh also appears to be experiencing reductions in son preference. Qualitative interviews from Matlab conducted in 2010 as part of our project suggest

that women now prefer one son and one daughter (Fraser 2011); it is possible that this balanced preference may be one factor driving reduced sex ratios over the past two decades. One possible source of these changing preferences is government campaigns for "one boy, one girl," though some studies of the effects of such messages suggest their effects on behavior are limited (e.g., Shenk et al. 2013). A more convincing reason for shifting preferences may be changing socio–ecological circumstances in rural Bangladesh; as men are increasingly absent due to labor migration, daughters are filling new social roles, including caring for aging parents in the absence of a son and/or daughter-in-law. Our qualitative interviews highlighted the cultural ideal of having a son to support a family financially and a daughter to support younger siblings or aging parents physically (Fraser 2011). Similar attitudes have been found in urban Bangladesh among poor working women (Ahmed and Bould 2004), suggesting this is a social phenomenon that is not limited to rural areas.

7.4.3   Policy Implications

What will happen in the future? While increasing dowries, rising incomes, and expanding labor migration would suggest a potential future rise in sex ratios in Bangladesh, it appears that these trends are being offset by lower levels of mortality, higher women's education, increasing age at marriage, and the shift away from agriculture. Additionally, even if many women remain housewives, our qualitative interviews suggest that men and their parents increasingly want educated, capable wives who are able to manage the family both economically and logistically in the absence of a labor migrant husband, as well as aid children (both sons and daughters) with their schoolwork. Thus, even if women are not laborers in the public sphere, the characteristics of their domestic labor may be shifting in a direction consistent with further increases in women's education, status, and autonomy.

Some authors suggest that the lack of ultrasound technology in Bangladesh, and rural Bangladesh in particular, has kept sex ratios low (Hesketh and Xing 2006). The concern is that if such technology were to become more widely available, underlying son preferences would manifest through sex-selective abortion as has happened in many parts of India. This does not seem likely to us. Various methods of manipulating sex ratio, such as sex-selective neglect and differential birth spacing and stopping using contraceptives, are currently available to people in Matlab. Yet despite increasing access to medical technology and contraceptives in the region, sex ratios have actually declined over the past two decades, something unlikely to have happened in the face of strong underlying son preference. Moreover, many parts of South Asia which have low sex ratios (e.g., Kerala, Sri Lanka) have access to the same technologies without an increase in sex ratio. We see no indication from our data that Matlab will return to higher sex ratios simply through the availability of ultrasound technology; in fact, all indicators suggest that sex ratios will stay low —or, more clearly, balanced—well into the future.

The low, gender-balanced sex ratios in modern Matlab suggest no need for policy action at present. However, our findings do suggest which types of policies might be effective in other areas where sex ratios are high or rising. Although cause and effect are difficult to determine, policies encouraging higher female education and later ages at marriage may be effective, as might policies which lower infant and child mortality. Concern about dowry may be justified with respect to sex ratio, though given the well-known ineffectiveness (or even counterproductiveness) of laws against dowry in India, this is probably not a promising policy avenue (e.g., Shenk 2007; van Willigen and Channa 1991).

Attempting to limit rising incomes or labor migration, on the other hand, would be not only ineffective but also counterproductive to many important development goals. Despite the potential effects of rising incomes on sex ratios, the Bangladeshi situation suggests that economic growth and falling sex ratios are not incompatible. Agriculture is becoming less common as an occupation throughout South Asia, which suggests the potential for lower sex ratios. Even so, the association between agriculture and higher sex ratios suggests that policy workers would do well to concentrate efforts to reduce child mortality, encourage girl's education, and delay marriage among agricultural families.

Finally, even though public policy discussions tend to view unbalanced sex ratios as a social problem, this need not always be the case, especially if the level of bias is modest. We urge policymakers to adopt a more nuanced perspective on sex ratios and their social implications. Despite the problematic conditions for unwanted daughters, families who seek to produce a particular mix of genders in the household are usually doing so for good reasons—to keep the family economically viable, to avoid competition for resources that might lead to conflict or privation, to provide for their own support in old age, or to ensure the survival of the family or lineage. Policymakers need to balance the well-being of one family member with that of other family members; after all, it is just this kind of balancing act that parents must engage in when allocating investment within the family.

7.5   Conclusions

Our analyses demonstrate the efficacy of an evolutionary demographic approach to understanding sex ratio variation within families and regions, as well as to refining policy recommendations with respect to sex ratio. Many of our findings coincide with those of mainstream demography, yet an evolutionary approach allows us to generate new predictions as well as weave shared findings into a broader theoretical framework. We encourage demographers to consider ultimate causation when exploring issues such as sex ratio bias, and we encourage evolutionary researchers to focus beyond the traditional models of sex ratio when considering the causes of child gender preference or biased sex ratios.

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