Sex Selection and Gender Balance*

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Abstract

We model parental sex selection and the equilibrium sex ratio. With intrinsic son preference, sex selection results in a male-biased sex ratio. This is inefficient, due to a marriage market congestion externality. Medical innovations that facilitate selection increase inefficiency. If son preference arises endogenously, due to population growth causing an excess of women on the marriage market, selection may improve welfare. These results are robust to allowing prices or intra-household transfers in a frictional market. We analyze the effects of sex ratio imbalances on parental investments, the effect of fertility on sex selection and concerns for family gender balance.

JEL Categories: J12, J13, J16

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In many parts of the world, parents exhibit gender bias, and prefer to have sons. This phenomenon is especially prevalent in South and East Asia. In Northern India, it is common to celebrate the birth of a boy and bemoan that of a girl. The community of *hijras* (eunuchs), who make their living by extorting money on joyous occasions such as the birth of a child, demand substantially larger amounts when the child is male. Gender bias is reflected in male biased sex ratios, and the problem of "missing women" (Sen, 1990), a problem that was already noted in the first Indian census of 1871. Historically, sex ratio imbalances have been attributed to the relative neglect of girls, but in extreme cases, infanticide has also been practised. In Dharmapuri district of Tamil Nadu, India, infant girls were often fed uncooked rice, as a way of inducing rapid death. In Punjab (northern India), the caste of Bedi Sikhs have traditionally been known as *kudi-maar* – "girl-killer".[1]

Modern medicine has aggravated the problem by facilitating selection for boys. The development and spread of amniocentesis and ultrasound screening in the early 1980s made foetal sex determination possible, permitting sex selective abortion. Sex selective abortion is illegal in China and India, but the practice flourishes. It is hard to see how such a law can be enforced given that neither ultrasound nor abortions are illegal, so that sex selective abortion is *unverifiable.* These technological developments have been associated with a rapid increase in the sex ratio at birth in East/South Asia, from its usual norm of 105-106 boys per 100 girls. In the Indian census of 2001 the sex ratio in the age group 0-6 was 107.8, with some northern states such as Punjab having ratios as high as 120-125 (Bhaskar and Gupta, 2007). In the 2000 Chinese census, the sex ratio in the age group 0-4 was 120.2, with some regions reporting ratios of 130-135. These trends are mirrored in other Asian countries such as South Korea and Taiwan, which have sex ratios at birth of 108 and 109 respectively. The large increases in the sex ratios across censuses are most plausibly due to the spread of sex selection techniques.[2]

The marriage market consequences of these sex ratio imbalances are enormous. Our empirical estimates suggest that in China, one in four boys in recently born cohorts will be without brides, raising fears of social disruption and instability. This raises the question, how can such imbalances persist? Asian parents may prefer boys to girls, but surely evolution has also endowed them with a strong desire for grandchildren. Can such sex ratios be an equilibrium phenomenon, or do they reflect myopia on the part of parents? These trends also raise the normative question, should we allow parental sex selection? The standard response, from governments, international agencies, and non-governmental organizations, is to deplore

[1] See Dasgupta (1987) on discrimination in the Punjab.

[2] For aggregate estimates of the extent of sex selective abortions in India, see Arnold et al. (2002) and Jha et al. (2006). Portner (2009) uses micro data on birth spacing in India to estimate the hazard rates of having a boy and a girl.

sex selection, since this reflects discriminatory preferences, that are based on ignorance and backwardness. Rather than allowing choice based on such preferences, the state has a duty to educate away such preferences. This view is squarely paternalistic, and policy is not based upon the preferences of citizens, but on those of enlightened agencies.

An alternative view, that is less common, is that sex selection may improve the position of girls, by raising their value as they become scarce. Dharma Kumar (1983) was an early and trenchant proponent of this position. She asked whether selective abortions are any worse than the neglect and infanticide of girl children, and argued that market forces will alleviate problems arising from discriminatory preferences. However, this view does not take into account possible externalities or market failure.

There is an enormous empirical literature on the subject of the sex ratio. Following Amartya Sen (1990) and many demographers (e.g. Coale, 1991), economists are increasingly contributing to this debate (see Oster, 2005; Qian, 2008; Anderson and Ray, 2009). However, there is very little in terms of formal economic analysis of the social implications of sex ratio imbalances arising from sex selection. Edlund (1999) examines the effects of sex selection in a finite and hierarchically ordered society. However, her work does not examine welfare issues, and does not address the congestion externalities and possible market failures that lie at the heart of the present paper.[3] Following R.A. Fisher (1930), biologists have examined models of equilibrium sex ratios; however, evolutionary models do not allow for any concerns apart from long run genetic representation, and do not deal with welfare issues.

Section 1 of this paper proposes a model of parental choice and the equilibrium sex ratios in order to address these issues. An imbalance in the sex ratio is an equilibrium consequence of gender biased preferences. At an equilibrium, the payoff difference between having a boy as compared to a girl will be lower than in the absence of choice. This is mainly done by reducing the payoff to having a boy, from reduced marriage market prospects; the payoff to having a girl also rises, but to a smaller extent. In consequence, parents who select for boys exert a congestion externality in the marriage market. Sex selection reduces welfare, where welfare is evaluated in terms of the ex ante expected utility of the typical parent. Technological improvements in selection that facilitate sex selection will worsen the sex ratio and reduce welfare. Our policy recommendation is a Pigouvian subsidy to girls, that is financed by a tax on boys – this results in a Pareto improvement.

Our conclusions are different if intrinsic gender bias is absent or mild, and if the observed preference for boys arises endogenously, from the fact that girls find it hard to marry. This may arise due to the *marriage squeeze* – the effective excess supply of girls in the marriage

[3]In section 4 we discuss sex selection in a class society, and in this context, we discuss Edlund's work in greater detail.

market, due to population growth and the fact that men marry younger women. If population growth causes an excess supply of girls, and there is little intrinsic gender bias, then sex selection may improve welfare. Thus, the answer to the question, does sex selection raise or reduce welfare depends upon empirical evidence. In China, census data shows that cohort sizes are falling rapidly, so there is reverse marriage squeeze, and a large excess supply of boys. Thus selection for boys is unambiguously welfare reducing. In India, the picture is more mixed. Cohort sizes are growing, and the marriage squeeze counteracts the marriage market consequences of biased sex ratios. There is an excess supply of boys in the North-West of India, and in this region, sex selection appears to be welfare reducing; however, elsewhere in the country, there is still an excess supply of girls on the marriage market.

The results of our model are robust to various extensions. As Angrist (2002) and Chiappori et al. (2002) show, an excess of males on the marriage market will raise the bargaining power of women and shift household allocations in their favour. Since parents are altruistic, this will make it more attractive for them to have girls rather than boys. Such distributional effects will reduce the magnitude of sex ratio imbalances, but our qualitative conclusions continue to hold. We show this in section 2, in a model where intra-household allocations are negotiated in marriage markets that are subject to search frictions. With large gender bias, the equilibrium sex ratio is excessively biased towards boys from a social welfare standpoint, and technological progress reduces welfare by aggravating the congestion externality.

Imbalances in the sex ratio also differentially affect parents incentives to invest in boys as compared to girls. In section 3 we examine the joint determination of sex ratios and parental investments. This requires a modification of the model of parental investments due to Peters and Siow (2002), since equilibrium fails to exist in their model once we allow for sex selection. Our analysis shows that a male biased sex ratio causes inefficiencies in investments – there is over-investment in boys relative to the first best, and under-investment in girls. However, if the social planner can ensure a balanced sex ratio (e.g. via a tax-subsidy scheme), then investment decisions will also be efficient. We also extend our model to consider a variety of other issues. In section 4 we consider how the incentive to select varies endogenously across social groups, so that selection decisions in upper classes will affect incentives in poorer sections. In section 5 we analyze the effects of fertility and family composition upon selection decisions. This provides a theoretical basis for understanding the effects of fertility decline (e.g. due to China's one-child policy) on the sex ratio.

In section 6 we consider developed societies where family gender balancing is a primary motivation. Sex selection is increasingly possible via "acceptable" technologies, such *in vitro* fertilization or preconception gender selection. Sex selection may improve individual utility; however, even if family balancing is the primary motive, a congestion externality may arise if preferences are not fully symmetric between the sexes, or if the costs of selection are gender dependent. Thus society must ensure that incentives are provided to ensure gender balance at the aggregate level. The final section concludes. The appendix provides details of the formal proofs that are not dealt with in the body of the paper.

1 The Basic Model

The standard biological model of the sex ratio dates back to R.A Fisher (1930), following on ideas in Darwin. Fisher's model is one where a parent is concerned only with maximizing reproductive fitness, and predicts a balanced sex ratio. In equilibrium, there is no gender bias – parents are equally happy when a girl is born as when a boy is. However, human societies have been transformed enormously from the times of hunter-gatherers when evolutionary preferences were shaped. With increased life expectancy, children are an important source of support in old age. Thus the economic value of offspring, beyond considerations of genetic representation, is also important. Different agricultural technologies afford varying roles for the sexes. Boserup (1970) argued that the superior status of women in sub-Saharan Africa relative to Asia was attributable to their greater utility in hoe-cultivation as compared to plough-cultivation. Bardhan (1974) attributes the higher status of women (and favorable sex ratios) in rice-growing south India, relative to wheat-growing north India, to the fact that rice has greater use for female labor than wheat. More recently, Qian (2008) investigates the effects of the change in gender specific earnings caused by the Chinese economic reforms, that raised the returns to female labor in tea growing regions, and to male labor in regions with orchard fruit. She finds significant inter-regional changes in the sex ratio that are associated with regional cropping patterns.

Cultural factors may also reinforce son preference. For Hindus, a son is deemed essential, since it is he who must light the funeral pyre. Confucianism assigns a pivotal role to the son-father relationship. Economists may seek deeper explanations for these cultural phenomena; however, these historically given preferences play a role in determining current behavior.

These considerations suggest that while concerns of reproduction are important, the economic (and cultural) value of offspring is also relevant. Accordingly, we modify Fisher's model by allowing parents to have preferences directly regarding the gender of their child. Our primary focus is on the effects of "gender-bias" in preferences, possibly arising from differences in economic value of the sexes, although we also investigate "family-balancing" concerns in sections 5 and 6. To this end, we assume that parental preferences are such that a boy is preferred to a girl, conditional on both having the same marital status. However, a married girl is strictly preferred to a single boy. Since marriage is uncertain, we need to consider preferences over lotteries, and we parameterize the von-Neumann Morgenstern utilities as follows. Let u_B be the base payoff to the parents from having a single boy, and let u_G be the base payoff from having a girl. We assume that each boy is ex ante identical; however, his quality in the marriage market is random and equals $\rho_G + \varepsilon$, where $\rho_G > 0$ and ε has a continuous density on support $[0, \bar{\varepsilon}]$. Thus, any girl has a payoff ρ_G from marriage, and the term ε reflects the idiosyncratic quality of her partner's quality. Similarly, all girls are ex ante identical, and her realized quality equals $\rho_B + \eta$, where $\rho_B > 0$ and η has a continuous density on support $[0, \bar{\eta}]$ with the same mean as ε. We assume that the idiosyncratic component of match value is small relative to the systematic component – this is stated precisely as Assumption A1. Assume that $u_B + \rho_B \geq u_G + \rho_G$ – for most of the paper, we assume that this inequality is strict i.e. there is son preference. Furthermore, we shall assume that a married girl is always preferred to a single boy i.e. $u_B < u_G + \rho_G$. We assume that the quality of the child cannot be observed at conception (although gender can), but only later, on the marriage market. We also assume that parents evaluate matches in the same way that their offspring do.

We now turn to supply and demand in the marriage market, which depend not only on the sex ratio but also upon the rate of growth in birth cohort size. This is due to the fact that men are, on average, older than their wives. Data from the United Nations (1990) documents that this is true in each of over 90 countries, in each time period (between 1950 and 1985) that data is available. While an age gap at marriage may not cause any imbalances in a stationary population, it has major social consequences when cohort sizes are increasing over time, since each cohort of men is matched with a larger cohort of women. The consequent excess supply of women has been called the *marriage squeeze,* and it weakens women's' position on the marriage market. Demographers, such as Bhatt and Halli (1999), have argued that the marriage squeeze is responsible for the deterioration of the position of women in India, and replacement of the institution of bride price in many regions and communities by dowries (payment from the bride's family to the groom). Let g be the rate of growth of cohort size, and let $\bar{r}$ be the sex ratio at birth (of girls relative to boys). Let τ be the age gap at marriage, assumed to be exogenous – on page 9 we discuss the implications of endogenizing τ. To simplify notation, let $\gamma = (1 + g)^{\tau}$.Thus the ratio of women to men in the marriage market, r, is related to the sex ratio at birth, $\bar{r}$, by the equation $r = \gamma\bar{r}$. For expositional simplicity, we shall assume positive growth, so that $\gamma \geq 1$ – the implications negative growth are easily inferred from our analysis.[4] Given population growth, our analysis focuses on a dynamic steady state equilibrium, where the sex ratios at

[4] This is realistic for most developing countries, except China, where cohort sizes appear to be falling, due to the impact of the one-child policy.

birth and in the marriage market are constant.

We now consider matching in the marriage market, between men born at any date t and women born at $t+\tau$. We assume perfect matching, without any frictions, and require a matching to be measure preserving, and *stable,* in the sense of Gale and Shapley (1962).[5] In our context, it is well known that a stable measure preserving matching is essentially unique, and will be positively assortative. That is, if a boy of realized quality ε is matched to a girl of realized quality $\phi(\varepsilon)$, then

$$1-F(\varepsilon)=r[1-G(\phi(\varepsilon))],$$

where $F(.)$ and $G(.)$ denote the cumulative distribution functions of ε and η respectively. If $r<1$, then the lowest quality boys, i.e. a proportion $1-r$, will be left unmatched. Let $\underline{\varepsilon}= F^{-1}(1-r)$ denote the lowest quality boy that is matched in this case. If $r>1$, the lowest quality girls, of proportion $1-\frac{1}{r}$, will be left unmatched. Let $\underline{\eta}= G^{-1}(1-\frac{1}{r})$ denote the lowest quality girl that is matched.

Since the quality of the offspring is unknown at the time of conception, the ex ante expected utility of having a boy, as function of the sex ratio, is given by

$$U(r)=\begin{cases} u_B+r[\rho_B+\mathbf{E}(\eta)] \text{ if } r<1 \\ u_B+\rho_B+\mathbf{E}(\eta|\eta\geq\underline{\eta}) \text{ if } r\geq 1 \end{cases}.$$

Similarly, the ex ante expected utility of having a girl is given by

$$V(r)=\begin{cases} u_G+\frac{1}{r}[\rho_G+\mathbf{E}(\varepsilon)] \text{ if } r\geq 1 \\ u_G+\rho_G+\mathbf{E}(\varepsilon|\varepsilon\geq\underline{\varepsilon}) \text{ if } r<1 \end{cases}.$$

Suppose now that sex selection is very costly, so that it is never exercised. We shall assume in this paper that the natural sex ratio at birth is 1.[6] The sex ratio in the marriage market is given by the rate of growth of cohort size, γ. Thus the payoff difference between having a boy and having a girl is given by

[5] That is, if M is the set of men and W is the set of women, a matching is a function $\phi:\mathsf{M}\to\mathsf{W}\cup\{0\}$ that satisfies the following properties. First, if $w=\phi(m)$, then w is not the image of any other $m'\in\mathsf{M}$ under ϕ, i.e. any woman can be matched only to a single man. Second, if $\mathsf{M'}\subset\mathsf{M}$, the Lebesgue measure of $\mathsf{M'}$ equals that of the set $\phi(\mathsf{M'})$. Third, if $w=\phi(m)$, then both m and w prefer to be matched to each other rather than being single. Finally, if $w\neq\phi(m)$, then either m prefers $\phi(m)$ to w or w prefers her current match to m.

[6] The natural sex ratio at birth is about 0.95; however, boys usually have higher mortality than girls, although this appears not to be the case in India and China (Anderson and Ray, 2009). Our results do not depend very much on this divergence, since our focus is on selection, where the sex ratio diverges from the natural one.

$$[u_B + \rho_B + \mathbf{E}(\eta | \eta \geq \underline{\eta}] - [u_G + \frac{1}{\gamma}(\rho_G + \mathbf{E}(\boldsymbol{\varepsilon}))] \; > 0.$$

If cohort sizes are increasing, then boys are preferred to girls not only due to possible son preference (i.e. if $u_B + \rho_B > u_G + \rho_G$) but also due to the fact that girls have poorer marriage market prospects – boys will be matched for sure and secure a higher quality partner, while girls are matched only with probability $\frac{1}{\gamma}$.

Let the cost of sex selection be sufficiently small that it will be exercised. Consider first the case of ex post selection, e.g. via sex selective abortions. In this case, a pregnant mother observes the sex of foetus and can pay a cost c to have an abortion and conceive another child. Suppose that the foetus is female, and has value $V(r)$. By having an abortion and trying again, the parent gets the ex ante expected utility of a child, which is given by $\frac{1}{2}\{U(r) + V(r)\}$, minus the cost. So aborting the foetus and trying again is optimal if $U(r) - V(r)\} \geq 2c$, while accepting the girl child is optimal if this inequality is reversed. In the case of *in vitro* fertilization, choice is exercised ex ante, before pregnancy. If the parents select for a boy, they are assured of the certain payoff, $U(r) - c$, where c now represents the cost of *in vitro* fertilization. By not exercising choice, the parents get the lottery with payoff $\frac{1}{2}\{U(r) + V(r)\}$. Thus the incentives for exercising choice are formally identical to the case of ex post selection, even though choice is associated with the uncertain outcome in the case of abortions, and with the certain outcome in the case of *in vitro* fertilization.[7] However, the magnitude of the cost involved in selection (c) is likely to be dramatically different in the two cases, since *in vitro* fertilization is much more acceptable from a psychological, ethical and social point of view. The analysis is easily extended to the case of imperfect ex ante selection technologies, such as sperm selection – if the probability of having a boy is $p > 0.5$, then the relevant cost is $\frac{2c}{2p-1}$ rather than $2c$.

Suppose that $2c < U(\gamma) - V(\gamma)$. It is clear that $r = \gamma$ cannot be an equilibrium, since the value of trying again is greater than the cost. At the unique equilibrium, the sex ratio r^* must be interior (i.e. in $(0, 1)$), so it must be the case that a parent is indifferent between accepting a girl child and trying again. This gives us the basic indifference condition:

$$U(r^*) - V(r^*) = 2c. \tag{1}$$

The intuition for this condition is straightforward: by exercising choice when one has a girl, a parent gets an improvement in value from $V(r^*)$ to $U(r^*)$, with probability one half.

[7] This equivalence follows from the assumed separability between gender specific payoffs and the cost of selection. Also, if there is an endowment effect, then this could make accepting the status quo (the girl child) more valuable in the case of ex post selection. These considerations are likely to be dwarfed by the difference in direct psychological costs associated with the two technologies.

Indifference requires that the expected value of this equals the cost c.

Consider first a society where $\gamma > 1$, so that there is population growth but where gender bias in preferences is mild or non-existent so that $(u_B+\rho_B)-(u_G+\rho_G) < 2c$. The equilibrium sex ratio in the marriage market, r^*, must be greater one in the absence of significant gender bias. To see this, observe that when the marriage market is balanced, $U(1)-V(1)-2c < 0$, so that it is not worthwhile to select for boys. However, selection for boys must take place if the sex ratio is to fall below γ, and the indifference condition (1) must be satisfied. Thus, the equilibrium sex ratio in the marriage market, r^*, must exceed one, while the sex ratio at birth, $\bar{r}$, will be less than one.

Now let us consider a society where there is significant gender bias in preferences, so that $(u_B + \rho_B) - (u_G + \rho_G) > 2c$. In this case, parents will prefer to select for boys when the marriage market is balanced. Thus the equilibrium sex ratio, r^*, must be less than one, and selection will aggravate the imbalance in the marriage market due to population growth rather than alleviating it.

To summarize: if cohort sizes are growing, costly sex selection will alleviate the imbalance in the marriage market, but not entirely eliminate it, if parental gender preferences are unbiased or if the bias is relatively mild. However, if there is significant gender bias in preferences, there is an oversupply of boys in the marriage market. Our analysis also shows that no matter whether we have large gender bias or not, the equilibrium marriage market sex ratio r^* does not depend upon the rate of population growth, γ. This is clear from the indifference condition (1) – neither $U(r)$ nor $V(r)$ depend upon γ.[8] This implies that the sex ratio at birth adjusts to variations in γ, so as to keep r^* invariant.

We may also ask, what is the implication of the proportion of boys in births being different from 0.5? This is relevant in the context of the argument by Oster (2005) that hepatitis B infection raises the share of boys in births, and is responsible in large portion for the excess of boys in China. [9] However, this assumes that there is no behavioral response by parents to the incidence of the virus, as Oster acknowledges. Let p denote the probability of having a boy, as assessed by the parents. The equilibrium marriage market sex ratio r^* depends only on the assessed p, and via the indifference condition, which must be re-written as $U(r^*) - V(r^*) = \frac{c}{p}$. Thus the effect on the equilibrium sex ratio depends upon whether parents are aware of the link between hepatitis B and the sex ratio at birth. If they are

[8] This is subject to the caveat that we are at an equilibrium with selection; otherwise (i.e. when there is little gender bias and when γ is small), this is not true, since $r = \gamma$.

[9] This has been questioned by a number of authors, and qualified by Oster herself. Most compelling are the findings of Lin and Luoh (2008). They use Taiwanese data on the mother's hepatitis B status at the time of pregnacy, and find that this does not contribute significantly to explaining imbalances in the sex ratio at birth.

unaware, as seems most likely given that this is a relatively new hypothesis even in the scientific community, then they continue to assume that $p = 0.5$. Thus, r^* and the sex ratio at birth do not change, and the behavioral response completely offsets any direct effect of hepatitis B upon the sex ratio at birth. If mothers are aware of the link (but not of their own hepatitis B status), then the equilibrium sex ratio will be given by the modified indifference condition, and thus the behavioral response partially offsets the direct effects. We refer the interested reader to the discussion paper version of this paper for a more complete analysis of this issue. This analysis also applies if there is any reason why p may differ from 1. For example, the natural ratio at birth in appears to be around 0.94 or 0.95, and mortality data show that this excess of boys is not offset by differential mortality in the case of India and China (see Anderson and Ray, 2009).

We have assumed that the age gap in marriage, τ, is fixed. In separate work, I analyze how the age gap corresponding to a Gale-Shapley style stable matching responds to variations in population growth, g. Suppose that men and women have single-peaked preferences over the age gap at marriage, with men having an ideal age gap $\tau_B > 0$, while the women's' ideal gap is $\tau_G > 0$. With non-transferable utility, the equilibrium age gap τ will equal the ideal point of the short side of the market. That is, it will be equal to τ_B if there is excess supply of women in the marriage market, and τ_G if there is an excess supply of men. If the marriage market is balanced, then there can be multiple equilibria, with τ taking any value between the two ideal points. Thus our assumption that τ is fixed corresponds to the case where $\tau_G = \tau_B$. If the ideal points differ, then the age gap is *relatively insensitive* to changes in the sex ratio, since it changes only when market conditions change from excess supply to excess demand. More generally, it is not the case that the age gap adjusts to reduce excess supply in the marriage market. If gender bias is large, there will be excess supply of men in the marriage market, and the equilibrium age gap will be τ_G. There is an indirect effect of the endogeneity of τ upon r^* – women get a higher payoff since $\tau = \tau_G$, and this raises $V(r)$ and reduces $U(r)$, thereby increasing the equilibrium sex ratio r^*. Similarly, in the absence of gender bias, there will be an excess supply of women due to the marriage squeeze, and this means that $\tau = \tau_B$. This has direct effects on $\bar{r}$ and, indirectly, a negative effect on r^* by raising men's payoffs and reducing women's.

Welfare implications

Let us now examine the welfare implications of parental choice. The literature on sex selection in societies with gender bias has assumed that sex selection is immoral per se. Indeed, sex selective abortions have been termed "genocide" or "gendericide".[10] This however begs several question. In the societies under discussion (e.g. India or China), abortion is

[10] Gendericide is a neologism that refers to the mass killing of members of a specific sex.

legal and also morally acceptable, implying that these societies do not endow the foetus with an unconditional "right to life". If this is indeed the case, then why are selective abortions deemed immoral? Even if society is able to prevent sex selective abortions, it cannot ensure that the unwanted girls are loved and taken care of. Furthermore, newer selection technologies such as *in vitro* fertilization or preconception gender selection are less open to absolutist moral objections. In this paper, we assume a non-paternalistic welfare evaluation, and consider the welfare of the individual parent. Since all parents are ex ante identical (before the realization of the sex of their child), we take as our welfare criterion the expected ex ante utility of a typical parent – this also equals the sum of realized utilities of the parents in this society. Thus welfare, as a function of the sex ratio r, is given by

$$W(r) = \frac{1}{1+\bar{r}}U(r) + \frac{\bar{r}}{1+\bar{r}}V(r) - c\frac{1-\bar{r}}{1+\bar{r}}. \tag{2}$$

That is, a proportion $\frac{1}{1+\bar{r}}$ of parents have boys, and get utility $U(r)$, while the remainder have girls and utility $V(r)$. The third term is the cost associated with changing the sex ratio at birth from 1 to $\bar{r}$. Suppose that the social planner can choose the level of r, and consider how she might choose in order to maximize welfare function – we shall see that tax/subsidy schemes can serve as instruments. The derivative of welfare with respect to r equals

$$W'(r) = \frac{[V(r) + 2c - U(r)] + (1+\bar{r})[U'(r) + \bar{r}V'(r)]}{\gamma(1+\bar{r})^2} \tag{3}$$

$U(r)$ and $V(r)$ are differentiable everywhere except at $r = 1$, with derivatives :

$$U'(r) = \begin{cases} \rho_B + \mathbf{E}(\varepsilon) & \text{if } r < 1 \\ \frac{\mathbf{E}\left[\eta|\eta \geq \underline{\eta}\right] - \underline{\eta}}{r} & \text{if } r > 1 \end{cases}.$$

$$V'(r) = \begin{cases} \frac{\underline{\varepsilon} - \mathbf{E}\left[\varepsilon|\varepsilon \geq \underline{\varepsilon}\right]}{r} & \text{if } r < 1 \\ -\frac{\rho_G + \mathbf{E}(\eta)}{r^2} & \text{if } r > 1 \end{cases}.$$

If $r < 1$, then an increase in r raises male utility by increasing the probability that a boy finds a partner. It also reduces female utility, since lower quality males are also matched; however, since the idiosyncratic component of match quality is assumed to be small relative to ρ_B, the positive effect on males outweighs the negative effect on females. Similarly, when $r > 1$, a reduction in r has a positive effect on females, which is greater in absolute value than the negative effect on males.

Consider the derivative of welfare with respect to r, (3), evaluated at the equilibrium r^*. The first term in the numerator equals zero, since the indifference condition (1) holds at equilibrium. Thus, the sign of the derivative equals that of $U'(r) + \bar{r}V'(r)$, evaluated at r^*.

This depends upon whether r^* is less than or greater than one, and given by

$$[U'(r) + \bar{r}V'(r)]|_{r=r^*} = \begin{cases} \rho_B + \mathbf{E}(\eta)) - \frac{\mathbf{E}[\varepsilon|\varepsilon \geq \underline{\varepsilon}] - \underline{\varepsilon}}{\gamma} > 0 \text{ if } r^* < 1 \\ \frac{1}{r}\left\{\mathbf{E}(\eta|\eta \geq \underline{\eta}) - \underline{\eta} - \frac{\rho_G + \mathbf{E}(\varepsilon)}{\gamma}\right\} < 0 \text{ if } r^* > 1 \end{cases}.$$

If we assume that the idiosyncratic component of value (ε or η) is small relative to the systematic component ρ_G or ρ_B, then the derivative will be positive when $r^* < 1$ and negative when $r^* > 1$. Thus, if $r^* < 1$, then welfare is increasing in r, while if r^* is greater than one, welfare is decreasing in r. In the appendix we show that the global welfare optimum is at $r = 1$, so that if a social planner could control the extent of sex selection, she would aim for a sex ratio at birth that corresponds to a balanced marriage market. This requires an additional assumption, A1, that the idiosyncratic component on preferences is small relative to the average payoff of a boy or a girl, and that population growth is not extremely large.[11]

Assumption A1: $\bar{\varepsilon} \leq \gamma(\rho_B + \mathbf{E}(\eta))$, $\bar{\eta} \leq \frac{\gamma}{\gamma+1-\gamma^2}(\rho_G + \mathbf{E}(\varepsilon))$ and $\gamma + 1 > \gamma^2$.

Our results show gender bias results in a male biased sex ratio on the marriage market, and this is inefficient. The intuition for this inefficiency is as follows. Consider an equilibrium $r^* < 1$, and a parent who is selecting for a boy. If this parent decides not to select, she suffers no loss in payoff, since she is indifferent between selecting and not selecting at r^*. However, the decision not to exercise choice has a positive effect, since at the aggregate level, two more boys will find partners for sure. That is, there is a congestion externality in the marriage market which is not taken into account by parents who select.

However, selection has positive welfare effects in societies without large gender bias, by reducing the marriage market imbalance due to population growth and the age gap at marriage. In this case, selection exerts a positive externality, by reducing congestion. Here again, parents do not take this externality into account, and as a result, the equilibrium results in an unbalanced marriage market sex ratio, with too many girls.

Our welfare results have been obtained even though we take as our welfare criterion the expected utility of the typical parent, who may well have gender biased preferences. If we were to take into account the utility of the children, and use a utilitarian social welfare function, this would only reinforce our conclusions, since we may assume that girls do not have a preference to be boys instead. Thus the welfare gains from a balanced sex ratio would be larger in this case.

We now consider the implications of changes in c upon equilibrium welfare, at an interior equilibrium where the indifference condition (1) is satisfied. Let $W^*(c)$ denote equilibrium

[11] The assumption on population growth is satisfied in all existing societies. Assumption A1 is not symmetric with regards to the payoff parameters on boys and girls. This is due to population growth, and the fact that welfare criterion weights the utilities of the sexes according to their proportions at birth, which must be unequal if the marriage market is balanced.

welfare as a function of c, i.e., $W^*(c) \equiv W(r^*(c))$. Since it is optimal at r^* for a parent to accept the child that nature deals her, this can be written as

$$W^*(c) = 0.5\{U(r^*(c)) + V(r^*(c))\}.$$

Since the difference between $U(r^*)$ and $V(r^*)$ equals $2c$, this can be re-written as

$$W^*(c) = V(r^*(c)) + c.$$

From the indifference condition that determines r^*, $\frac{dr^*}{dc} = \frac{2}{U'(r)-V'(r)}$. So the effect of welfare is given by

$$\frac{dW^*}{dc} = 1 + \frac{2V'(r)}{U'(r) - V'(r)}.$$

$V'(r) < 0$ and $U'(r) > 0$, and so the second term is negative. Thus the effect on welfare of an increase in cost is positive when $|V'(.)| < |U'(.)|$ and negative otherwise. So when $r^* < 1$, since $|V'(.)| < |U'(.)|$, an increase in c increases welfare, since the equilibrium sex ratio becomes more balanced. In other words, technological progress, that makes selective abortions easier, reduces welfare, if the equilibrium sex ratio already has an excess of boys. On the other hand, if $r^* > 1$, a reduction in c makes the sex ratio more balanced, and thus increases welfare.

We summarize our results in the following proposition.

Proposition 1 *If there is large son preference ($(u_B + \rho_B) - (u_G + \rho_G) > 2c$), sex selection biases the equilibrium sex ratio, and results in a socially inefficient outcome, with too many boys. If there is little or no son preference ($(u_B + \rho_B) - (u_G + \rho_G) < 2c$), and the marriage market imbalance is due to population growth and the age gap at marriage, then sex selection increases welfare, and is insufficient at the equilibrium, since there is an excess supply of girls on the marriage market. In either case, social welfare is maximized when the sex ratio in the marriage market is balanced, provided that assumption A1 is satisfied. Technological progress that reduces the cost of selection, c, reduces welfare if the marriage market equilibrium has an excess of boys; it raises welfare if there is an excess of girls.*

It may be plausibly argued that the recent increases in the sex ratio in China and parts of India are not an equilibrium phenomenon, in the sense that parents may have incorrect expectations regarding the aggregate sex ratio and future marriage prospects. Learning models suggest that societies will be able to learn rational expectations equilibria in stable environments; however, recent technological developments have been so rapid that one cannot assume that expectations are rational. Since our welfare results are global, they apply also in this case, in the sense that selection is welfare reducing if the marriage market has an excess of boys (and is welfare improving otherwise). Thus if expectational errors result in an over-reaction of the sex ratio, the adverse welfare effects of selection are aggravated.

Table 1: Required & Actual Number of Boys per 100 Girls

	g	τ	required # boys	# boys	gap
China (total)	-5.0	1.8	91.2	120.2	+29.0
China (Han)	-5.4	1.8	90.5	121.2	+30.7
China (non Han)	-2.6	1.8	91.4	112.8	+17.4
India (total)	3.4	4.6	116.8 (112.9)	107.8	−8.0 (-5.1)
West	4.3	4.5	120.9 (115.7)	110.6	−10.3 (-5.1)
Central	3.5	3.8	114.1 (110.2)	108.3	−3.9 (-1.9)
South	2.8	5.5	116.5 (113.3)	105.0	−11.2 (-8.3)
East	2.6	5.0	113.9 (111.0)	105.1	−8.8 (-5.9)
North East	1.5	5.6	108.9 (107.0)	103.6	−5.3 (-3.4)
North West	2.9	2.8	111.5 (108.3)	122.2	10.7 (11.9)

Notes: g : in China, based on a regression of cohort size upon age (between 2 and 8) in 2000 census. in India, based growth rate of population age 0-6 between censuses of 1991 and 2001. τ : difference between singulate mean ages at marriage for men and women. China: data from United Nations, 2003. India: Census report (1991b). Column 3 and 5 figures in brackets are with τ adjusted down by 1 year.

Proposition 1 implies that the answer to question, is sex selection welfare reducing or not, is an empirical one. Table 1 shows computations of the of the situation in the marriage market of the future in China and India, based on the situation in the birth cohorts immediately preceding the censuses of 2000 (China) and 2001 (India). For China, we present figures for the overall population, the majority Han population (who comprise almost 90% of the population) and for the minorities. India is more linguistically and culturally heterogeneous, and we therefore present figures for the major geographical regions.[12] Column 1 is an estimate of g, the rate of growth of cohort size. Column 2 reports the age gap at marriage, which is calculated as the difference between the singulate mean age at marriages for men and women. Column 3 is an estimate of the required number of males per 100 females – it is effectively a calculation of $\gamma = (1+g)^{\tau}$, times 100. We have made an adjustment for the difference between mortality rates for females and males, between the ages 5 and 20, as computed in Anderson and Ray (2009), but this adjustment has quantitatively negligible

[12] We have also computed these figures at state level (this is probably most appropriate for the marriage market, given that states are oganized on a linguistic basis), but do not present these for reasons of space.

effects for the sex ratio in the marriage market.[13] The figures in brackets in column 3 are estimates for India where the age gap at marriage in column 2 is reduced by one year.[14] Column 4 reports the actual sex ratios, in terms of males per 100 females. The final column reports the gap between required and actual number of males per 100 females.

The results of Table 1 are striking. In China, cohort sizes are shrinking rapidly, at 5% per annum, even though population growth is positive. Even with a small age gap at marriage, of 1.8 years, this results in a large *reverse* marriage squeeze. Proposition 1 therefore implies that welfare optimality requires selection for girls. However, the sex ratio at birth shows a large excess of boys. The marriage market is predicted to have over 30 extra boys per 100 girls. This is enormous – one in four boys amongst those born around the year 2000 will not find a partner in future. Since 37 million boys were in the age group 0-4, over 9 million of them would be doomed to remain single. In the age group 0-9, over 21 million are be predicted to remain single. The conclusion, that sex selection in China is welfare reducing, is hard to escape.

The situation in India is quite different. Despite the slowdown in population growth in recent years to less than 1.5% per annum, cohort sizes are growing at more than double that rate, at 3.4%. Coupled with a large age gap at marriage, this implies that marriage market balance requires a more male biased sex ratio than the one that actually prevails. At a more disaggregated level, when one looks at the situations across regions, we find that in the North-West of the country, where there are highly male biased sex ratios (120 boys per 100 girls), there is an excess supply of boys. Elsewhere, we find that there is a significant excess supply of girls. This is particularly large in the Southern states, due both to the fact that the sex ratio at birth is more favorable in these states, and due to the larger age gap at marriage in the South as compared to the North. These empirical findings, both for China and India, appear to be novel, since they based on the rates of growth of cohort size.[15]

This evidence implies that sex selection has adverse social consequences in China, so

[13] Anderson and Ray (2009) find that for India, differential mortality between the ages 5 and 20 results in an extra 0.2 males per 100 females. Since the actual sex ratio in India in column 4 pertains to the age group 0-6, this is the appropriate correction. In China, differential mortality up to age 24 adds 4.1 males per 100 females; however, most of this difference is attributable to the higher mortality of girls in infancy. The actual sex ratio for China in column 4 is the average until age 4. Since differenctial morality after age 4 is negligible, this correction has negligible effects. We also do not make any adjustment for polygyny, since this is quantitatively insignificant in both China and India.

[14] The age gap at marriage is defined as the difference between the singulate mean ages at marriage of men and women, and reflects the age gap in the stock of married individuals, rather than current marriages. The downward adjustment by one year is an attempt to take into account the fact that the age gap at marriage is declining in India – over a twenty year period, the age gap fell by 1.2 years.

[15] For example, Neelakantan and Tertilt (2008) compute marriage market sex ratios based on population growth figures. These differ considerably from cohort size growth, for both India and China, and the difference is magnified due to compounding over the age gap.

that the current Chinese policy banning sex selective abortions may be well motivated. India also has a ban, and this may have foundation for the North West. However, a ban seems unworkable, since it is impossible to verify that a sex selective abortion has indeed taken place. However, there are alternative Pigouvian balanced budget tax-transfers that can incentivize parents to have girls. These would work by increase the value of girls to parents while reducing that of boys, e.g. via differential school fees or by explicit subsidies. Suppose that the government subsidizes each girl by an amount s_G, and taxes each boy an amount t_B. If the levels of these are set so that $u_B + \rho_B - t_B - 2c = u_G + \rho_G + s_G$, then parents will be indifferent between boys and girls when the sex ratio in the marriage market is one. Since budget balance can be ensured by setting $\gamma t_B = s_G$, we have balanced budget tax subsidies that result in a Pareto improvement, and can ensure the socially optimal outcome.

Policy makers have recently taken steps in this direction – for example, on 3 March 2008 IANS reported that "in a move to stop female feticide and stabilize the skewed sex ratio, the Indian government announced an insurance cover for poor families with girl children that will see incentives at every step - when she is given vaccinations, sent to school and not married off before 18...The scheme would be first started in seven educationally backward states as a pilot project and later extended to the entire nation." However, this scheme seems partly motivated by redistributive considerations, since it was introduced mainly in the poorest regions in the country, where male biased sex ratios are not a serious issue – only one of the pilot regions is located in the North-West. Furthermore, as we shall see in section 4, there are theoretical reasons why selection for boys will be more significant in the upper classes than among the poor. Thus well designed tax-transfers, that are targeted to address the congestion externality directly, have yet to be introduced.

2 Intra-household allocation & the sex ratio

A shortage of women in the marriage market is likely to improve their bargaining power and their share of household resources (Becker, 1981). Angrist (2002) finds that a reduction in the sex ratio r in immigrant marriage markets in the US reduces the labor supply of women and raises that of men. Chiappori et al. (2002) estimate a structural model of distributional effects and find that a reduction in r reduces women's labor supply and increases their share of household resources, while raising the labor supply of men. These distributional effects have implications for parental selection decisions. If parents are altruistic, they will take into account the effects of the sex ratio upon the utility of their child. Parents whose children are on the short side of the market may also be able to capture a portion of these scarcity rents in the form of bride prices or dowries. Finally, these changes in the sex ratio may alter existing social norms and relations between children and their parents. It has been argued that parents prefer sons in India and China since traditionally sons support their parents in old age while daughters do not. If the bargaining power of daughters increases within the marriage, they may have a greater say on the pattern of inter-generational transfers and these norms may change.[16]

To model these effects, we now allow intra household allocation to be negotiated between the parties at the time of marriage. We would like household allocations to vary continuously with the sex ratio, as the above cited empirical evidence suggests. To this end, we embed the bargaining process in a marriage market subject to search frictions that defines the outside options of the parties. Consider an infinite horizon continuous time model, where u_B and u_G now represent flow payoffs from having a boy and a girl respectively, and i denotes the interest rate. Let ρ be the flow payoff from marriage for each partner.[17] Let t be the net transfer of household resources from the man to the woman – a negative value of t corresponds to a transfer from the woman to the man. Let $\xi(t)$ be the value to the woman of this transfer. Perfect transferability corresponds to the case where $\xi(t) = t$, while under imperfect transferability, $\xi(t)$ is strictly concave, with $\xi(0) = 0$ and $\xi'(0) = 1$. We shall also assume that both partners are able to make binding commitments regarding the division of the payoff for the duration of the marriage.[18] Parents take into account the effects of the transfers, so that the value to a parent, from a married boy, and a married girl, are given by:

$$U^m = \frac{u_B + \rho - t}{i},$$

$$V^m = \frac{u_G + \rho + \xi(t)}{i}.$$

At any instant, there are stocks of unmarried boys and unmarried girls, of measures μ and $x\mu$ respectively, so that x denotes the sex ratio in the stocks. We shall assume that matches arrive according to a Poisson process, where the arrival rate is increasing in both stocks,

[16] A caveat is in order here – since support for aged parents takes place many years after the marriage, it may be hard for commitments at the time of marriage to be enforced.

[17] For simplicity, we assume that there is no idiosyncratic component to match value — – our analysis extends, at the cost of additional notational burden, to the where idiosyncratic component is small relative to search frictions. Our assumption that the payoff from marriage is the same for both parties is without loss of generality if there is perfect transferability of utility.

[18] The importance of commitment power has been emphasized by several authors, e.g. Lundberg and Pollak (2003). In the absence of commitment, the results will be similar to the model without transfers, unless parties are able to capitalize future transfers at the time of marriage, in the form of bride prices or dowries.

differentiable and a symmetric function of its arguments. We also assume constant returns to scale so that the analysis maybe conducted in terms of x, the sex ratio, without reference to absolute market size μ. Let $\alpha(x)$ (resp. $\beta(x)$) denote the arrival rate of matches for a girl (resp. boy), where $\beta(x) \equiv x\alpha(x)$. $\alpha(x)$ is strictly increasing in x, while $\beta(x)$ is strictly decreasing. Finally, we shall assume that matching becomes more efficient if the market is more balanced, i.e. the number of matches per unit population is single peaked, with a maximum at $x = 1$.The values of a single boy and a single girl depend upon the sex ratio x and upon the prevailing transfer t, and are

$$U(x,t) = \frac{u_B}{i} + \frac{\beta}{i(\beta+i)}(\rho_B - t).$$

$$V(x,t) = \frac{u_G}{i} + \frac{\alpha}{i(\alpha+i)}(\rho_G + \xi(t)).$$

The transfer t, from the boy to the girl, is determined by Nash bargaining between the two parties. That is the equilibrium transfer t^* is given by the Nash bargaining solution where the outside options are given by the values to remaining single, $U(x,t)$ and $U(x,t)$.[19] Now, in an equilibrium, the negotiated transfer between the matched pair, t^*, must itself be equal to the prevailing transfer in the market. This allows us to solve for t^* as a function of x, and this is defined implicitly by the condition

$$\frac{\rho + \xi(t^*)}{\rho - t^*} = \frac{\alpha(x) + i}{\beta(x) + i}. \tag{4}$$

Let $\tilde{U}(x) = U(x, t^*(x))$, and $\tilde{V}(x) = V(x, t^*(x))$ denote the value of singles as a function of x alone, given that $t = t^*(x)$. We can now determine the equilibrium sex ratio in the stock, x^*. This must be such that difference in values between boys and girls at the time of birth equals the expected cost of selection:

$$\tilde{U}(x^*) - \tilde{V}(x^*) = 2c. \tag{5}$$

We now turn to the relation between the sex ratio in stocks and that in the flow of births. Assume that the flow of new births is exogenously given at g, let θ be the fraction of births that are girls, and let the instantaneous death rate be δ. In a steady state the sex ratio in the stock must be stationary, giving us the relation

[19] Alternatively, we could assume that the outside options constrain the bargaining solution, but do not otherwise affect it. The specification we have chosen allows the maximal effect of the sex ratio upon the bride price. Alternative specifications would only make the equilibrium more inefficient.

$$\theta(x) = \frac{g + \delta\alpha(x)(x-1)}{2g}.$$

The equilibrium sex ratio in the flow of births is given by $\theta(x^*)$. Note that $\theta(x^*)$ equals 1 at $x^* = 1$ and is less than one if $x^* < 1$.

We show first that the equilibrium sex ratio x^* must be less than 1 if $u_B - u_G > 2ci$. For if this is the case, then at $x = 1$, $\tilde{U}(1) - \tilde{V}(1) = \frac{u_B - u_G}{i}$ (since the matching function is symmetric, $\alpha(x) = \beta(x)$ when $x = 1$) and thus it is optimal to try again on having a girl. However, the sex ratio will be less biased towards boys than in the absence of transfers. Furthermore, the sex ratio will be less biased the greater the degree of transferability of utility, i.e. the closer $\xi(t)$ is to being linear.

Consider now the implications of population growth and the age gap at marriage. We may model this by assuming that the proportion of the flow of girls, in the absence of selection, $\hat{\theta}$, is greater than one-half. In the absence of selection, the sex ratio in the stock will be $\hat{x} = \theta^{-1}(\hat{\theta}) > 1$. The corresponding equilibrium transfer, $t^*(\hat{x})$, is given by equation (4), and will be negative if $\hat{x} > 1$; thus marriage squeeze results in positive groom prices or dowries. t^* is a decreasing function of $\hat{x}$ (see appendix), implying that if the marriage squeeze intensifies, this increases the level of dowries. This provides an explanation for the increase in dowries in the twentieth century in India (see Rao, 1993), and their spread to parts of the country where they were not prevalent. It is important to clarify that an increase in population growth will raise dowries in a continuous way in a frictional market since there has been some controversy in the literature. Anderson (2007)) argues that the marriage squeeze cannot cause dowry inflation, but considers only a one-off increase in population, which then returns to its stationary level – this cannot cause a permanent increase in dowries. Also, she assumes perfect matching and transferable utility, and in such a world, the effect of sustained population growth on dowries would be discontinuous – there is a jump increase when population growth becomes positive, and no further increase with further rises in population growth, since dowries are already at their maximal level.

If $\hat{x} > 1$, $\tilde{V}(\hat{x}) < \tilde{U}(\hat{x})$. If c is sufficiently small, it is optimal to select for boys. Thus the equilibrium sex ratio x^* must satisfy the indifference condition (5). Consider now the case where gender bias is mild or absent, i.e. $u_B - u_G > 2ci$. In equilibrium, the payoff of boys must exceed the payoff of girls, so that that $x^* > 1$. The sex ratio in the marriage market is therefore biased against girls. Here again, the sensitivity of intra-household allocations or dowries to the sex ratio implies less bias than in the absence of such transfers.

Turning to welfare, the expected welfare of the parent is given by

$$W(x) = (1-\theta(x))\tilde{U}(x) + \theta(x)\tilde{V}(x) - (1-2\theta)c.$$

The derivative of welfare with respect to x equals

$$W'(x) = \left\{(1-\theta)\tilde{U}'(x) + \theta\tilde{V}'(x)\right\} + \left\{\theta'(x)[\tilde{V(x)} + 2c - \tilde{U}(x)]\right\}. \tag{6}$$

The first term in curly brackets is the "match efficiency effect" – how the (weighted) sum of the utilities of the two sexes responds to x. Match efficiency is concave in x and maximized at $x = 1$, i.e. when the market is balanced (see appendix). The second term in curly brackets is (a positive multiple of) the private benefit from accepting a girl as compared to trying again. Thus this term is strictly negative when $x > x^*$ and strictly positive if the inequality is reversed. This decomposition of equation (6) gives us two immediate results. Consider first the case of significant gender bias, so that $x^* < 1$. The equilibrium outcome is socially inefficient, with the sex ratio being too low, since at x^*, the second term is zero, and thus $W'(x)_{|x=x^*} > 0$. The social optimum x^{**} lies between x^* and 1, since at 1 the first term is zero and the second term is negative implying that $W'(x)_{|x=1} < 0$.We conclude therefore that welfare is increasing in x at x^*, i.e. the equilibrium proportion of girls is too low from a welfare point of view. Parental choice results in an inefficient outcome, with too many boys, since parents do not internalize the congestion externality in the marriage market.

In the case where there is little or no gender bias, and population growth so that $x^* > 1$, the social optimum x^{**} will be smaller than x^*, so that there is too little selection in equilibrium. Thus the main findings of our model of section 1 appear to be robust.

With frictional matching social optimality does not require $r = 1$. From equation (6), at $x = 1$ the match efficiency term is zero but the private benefit term is negative, and so welfare is decreasing in x. The welfare optimal level of x lies between x^* and 1.[20]

Our results here are related to the literature on job creation in search models of unemployment, as in Mortensen and Pissarides (1994). This literature finds that job creation is typically inefficient, although the direction of the inefficiency is ambiguous – there maybe too few or too many jobs. The difference is, in our context of parental choice, a child may enter on either side of the market – either as a boy or as a girl. The preference for boys over girls, coupled with the symmetry of the bargaining situation, permits an unambiguous conclusion – welfare increases by making the market more balanced. In particular, with large gender

[20]This is the one qualitative finding of the basic model of section 1 that appears not to be robust With frictionless matching, match efficiency is a non-differentiable function of the sex ratio, r, since the number of matches is equals the short side of the market. Thus the loss in match efficiency is first-order in $1 - r$. With frictions, the loss in match efficiency is of second order in the difference $(1 - r)$, implying that the optimal sex ratio is below 1.

bias, the equilibrium has too many boys, relative to the welfare optimum. In the job creation literature, Hosios (1990) has shown that appropriate assignment of bargaining power between the two sides can ensure an efficient allocation. In the present context, when there is large gender bias, efficiency requires that women have greater bargaining power than men, even when marriage markets are balanced. This seems somewhat unlikely given the inferior status of women in traditional societies. In an illuminating study on India, Bloch and Rao (2002) show that married men use domestic violence in order to extract additional payments from their in-laws. The irreversibility of marriage in traditional societies, in conjunction with the vulnerability of women within marriage, may move effective bargaining power towards men. Such an asymmetry would only aggravate the inefficiency that we find, resulting in a worse sex ratio, i.e. a lower equilibrium value of x.

We now examine the effects of technological progress, i.e. a reduction in c, upon equilibrium welfare, $W(x^*(c))$. Using the indifference condition, this can be written as

$$\begin{aligned} \frac{dW(x^*(c)}{dc} &= \left.\frac{\partial \tilde{V}}{\partial x}\right|_{x=x^*} \frac{dx^*}{dc} + 1. \\ &= \frac{2\tilde{V}'(x)_{|x=x^*}}{\tilde{U}'(x)\mid_{x=x^*} - \tilde{V}'(x)\mid_{x=x^*}} + 1. \end{aligned} \tag{7}$$

The results here are exactly parallel with those in section 1. When $x^* < 1$, $\tilde{V}'(x)\mid_{x=x^*} < 0$ is smaller than $\tilde{U}'(x)\mid_{x=x^*}$ in absolute magnitude, due to the match efficiency effect. Thus the first term is negative but greater than -1, and thus equilibrium welfare is an increasing function of c, since a higher value of c increases x^*. Conversely, when $x^* > 1$, technological progress increases welfare. We summarize our results as follows:

Proposition 2 *Consider a marriage market with frictional matching, where match efficiency is maximized when the sex ratio is balanced. If $u_B - u_G > ci$, both the equilibrium sex ratio and the welfare optimal sex ratio are biased towards boys, and the equilibrium has excessive boys compared to the welfare optimum. Technological progress that reduces c reduces welfare. Conversely, if $u_B - u_G < ci$, and there is a natural excess supply of girls due to the marriage squeeze, the equilibrium sex ratio has an excessive number of girls.*

Our main result, that the equilibrium sex ratio is inefficient in the presence of gender bias, is quite general, and applies as long as intra-household allocations vary continuously with the sex ratio. That is, as long as $t(.)$ is a continuous function, equilibrium requires adjustment in quantities as well as prices. This inefficiency can be avoided only if t varies discontinuously with x (or r), as in Walrasian models. In a Walrasian world, $t = \rho$ if there is an excess supply of men, but can take any value between $-\rho$ and ρ if the market is balanced. Thus a balanced sex ratio can be supported by a positive value of t that provides parents with sufficient incentives to avoid selecting for boys. The empirical literature (Angrist, 2002; Chiappori et al., 2002) adopts specifications where household allocations vary continuously with marriage market conditions. Our purpose here has been to obtain these results in the context of a fully micro-founded model, where transfers are determined by Nash bargaining, where the outcomes reflect the marriage market position of the two parties.

To summarize, when the sex ratio affects intra-household allocation in a continuous way, this reduces the magnitude of gender imbalances due to gender biased preferences but does not eliminate them. Our qualitative conclusions, that selection that results in sex ratio imbalances is welfare reducing, are unaffected. That is, the congestion externalities identified in section 1 continue to play a key role in determining welfare. The policy implications, that governments should subsidize girls and tax boys if the sex ratio has an excess of boys, is also reinforced.

3 Parental Investment

How do biases in the sex ratio affect parental care and investment decisions in children of the two sexes? This question is of great importance for the interpretation of micro evidence on health and educational investments. It is also relevant for understanding sex ratio effects on bride prices or dowries. If the agents on the long side of the market (e.g. boys) cannot make binding commitments to future intra-household transfers, then the only credible transfers must be in the form of bride prices. To the extent that capital markets are imperfect, the parents of boys must then save in advance to finance these bride prices.[21] This question is also empirically relevant. Wei and Zhang (2009) argue that the phenomenal increase in the Chinese savings rate is attributable to sex ratio imbalances, and the competitive pressure felt by the parents of boys. Furthermore, these investment decisions affect the relative payoffs to having boys and girls, so that we need to jointly determine gender selection and investment decisions in general equilibrium.

At the outset, one must distinguish, conceptually, between two types of investments, those that reduce infant or child mortality, and those that improve the "quality" of the offspring on the marriage market. Basic health care, such as immunization, are an example of the former, while education is an instance of the latter. The effects of the sex ratio on mortality reducing expenditures is straightforward. Since the value of girls is decreasing in r, while

[21] These arguments also apply if dowries are partly a form of pre-mortem bequests, as argued by Zhang and Chan (1999) and Botticini and Siow (2003), since the other partner also benefits.

the value of boys is increasing, an increase in r raises health expenditures in boys relative to girls. Several papers have documented gender discrimination in diet and in vaccinating children in India – see, for example, Dasgupta (1997), Pande (2003) and Barooah (2004). Thus, theory suggests that the marriage squeeze is in part responsible for these asymmetries in health expenditures, although gender bias also plays a part. With sex selection reducing the sex ratio, one should see these asymmetries being reversed.

More complex is the effect of the sex ratio upon parental investments that also raise the utility to the partner and thereby improve the child's position in the marriage market. These are subject to a potential hold-up problem, since parents may not internalize the benefits that the partner gets from these investments. Peters and Siow (2002) set out a model of pre-marital investments in a frictionless economy. There are fixed measures of boys and girls, each with an associated exogenous distribution of parental wealth. Peters and Siow focus on a rational expectations equilibrium, where the parent of a boy who invests x conjectures that the match quality of the partner will be given by a strictly increasing function $\phi(x)$, while the parent of a girl who invests y conjectures that her match quality will be given by $\phi^{-1}(y)$. These expectations have to be satisfied for investment levels that are actually chosen, but could be arbitrary for investment levels that are not chosen in equilibrium. They show that a rational expectations equilibrium is efficient, so that the hold up problem vanishes.

We now show that it is problematic to apply their analysis to our context, where the gender of the child is a choice variable, since an equilibrium will, in general, not exist under gender biased preferences. This arises due to a discontinuity in payoffs at $r = 1$. Assume that the parent derives a direct benefit $b_i(x)$ from an investment of x in a child of gender $i \in \{G, B\}$, and incurs a cost $\tilde{c}_i(x)$. Define the net cost of investment in a child, $c_i(x) = \tilde{c}_i(x) - b_i(x)$, and assume that this is strictly convex and eventually increasing. The Peters-Siow analysis implies that when the sex ratio is one, investment in either sex equals the efficient level, x_i^{**}, at a net cost $c_i(x^{**})$, where $c_i'(x_i^{**}) = 1$, since efficiency requires that the marginal cost equals the marginal benefit to the other partner, one. To make our argument most simply, suppose that the cost and benefit functions are the same for both sexes. Since both boys and girls invest the same amount, the payoff difference between a boy and girl equals $(u_B + \rho_B) - (u_G - \rho_G)$, which will be greater than $2c$ if preferences are sufficiently gender biased. Thus $r = 1$ cannot be an equilibrium.

Now let us consider a sex ratio $r < 1$. Let $x_B^{**}(r)$ and $x_G^{**}(r)$ be the efficient investment levels in boys and girls respectively. The Peters-Siow analysis implies that a measure r of boys will choose $x_B^{**}(r)$ and get matched for sure, while the remaining boys are unmatched. Thus a necessary condition for equilibrium is that the payoff to a boy is the same regardless of whether he is matched or not. But this implies that the payoff to a girl will be strictly larger: a girl is gets a payoff of $u_G + \rho + x_B^{**}(r) - c(x_B^{**}(r)) > u_B + \min\{c(x_B)\}$, which is the equilibrium payoff for a boy. Thus an equilibrium fails to exist when sex selection is possible. The problem is, there is a sharp discontinuity in payoffs – boys are preferred to girls when $r = 1$, but at $r < 1$, girls will be strictly preferred to boys since the payoff of a boy now equals that of one who is unmatched for sure.

We now show that equilibrium can be ensured by allowing for an idiosyncratic component of match value that is unrelated to investment, as we have been assuming in the present paper. If the investment in a boy is x, then the realized quality, as assessed by the partner is $x + \rho_G + \varepsilon$. Similarly, if the investment in a girl is x, then realized quality is given by $x + \rho_B + \eta$. We dispense with the assumption that the net cost function, c_i, is the same for both sexes — even if the gross cost function $\tilde{c}_i$ is identical, it is possible that parents are more altruistic towards boys more than towards girls, so that the benefits from investing in them could be larger.

Investment decisions given the sex ratio

Suppose that the sex ratio has been determined, so that the relative measure of girls to boys equals r. At the matching stage, since $r \leq 1$, all girls should be matched, and the highest quality boys should be matched. Since every girl is matched, the investment in her generates benefits for herself as well as for her partner, for sure. Thus the first best investment level in a girl, x_G^{**}, satisfies $c_G'(x_G^{**}) = 1$, i.e. the marginal cost (net of the benefit to her) equals the marginal benefit to her partner. Now consider investment in a boy. If we assume that the idiosyncratic component of match values is sufficiently small, then welfare optimality requires that only a fraction r of boys invest, and that their investments also satisfy $c_B'(.) = 1$. However, if we restrict attention to symmetric investment strategies, then investment will take place in all boys, and since investment occurs before ε is realized, each boy has a probability r of being matched. The first best efficient level of investment in a boy, x_B^{**}, must satisfy $c_B'(x_B^{**}) = r$, i.e. the marginal net cost must equal the expected marginal benefit to his partner.

Restrict attention to quasi-symmetric equilibria, where agents on the same side of the market choose the same investment levels. Let $x_i^*, i \in \{G, B\}$ denote equilibrium investments in gender i. A boy of type $\varepsilon \geq \underline{\varepsilon}$ will be matched with a girl of type $\phi(\varepsilon)$, where ϕ satisfies the condition $1 - F(\varepsilon) = r[1 - G(\phi(\varepsilon))]$. If a parent invests $x_B^* + \Delta$ in his son, the realized match for any ε will be that corresponding to $\varepsilon + \Delta$, $\phi(\varepsilon + \Delta)$. The matching process defines the benefits from additional investment – it improves a boy's match quality for any realization of ε, and makes it more likely that he is matched at all. At an equilibrium, the derivative of the expected payoff with respect to Δ equals zero at $\Delta = 0$:

$$\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} \phi'(\varepsilon) f(\varepsilon) d\varepsilon + f(\underline{\varepsilon})(\rho_B + x_G^*) = c_B'(x_B^*),$$

The left hand side of this equation has a natural interpretation. By investing a little more in my son, I improve his match quality by $\phi'(\varepsilon)$ for every realization of ε where he does get matched. I also increase his probability of getting matched, at a rate $f(\underline{\varepsilon})$, and in this event, his payoff equals that from being matched with the worst quality girl, $\rho_B + x_G^*$. Since $\phi'(\varepsilon) = \frac{f(\varepsilon)}{rg(\phi(\varepsilon))}$, the first order condition for investment in boys can be re-written as[22]

$$\frac{1}{r} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} \frac{f(\varepsilon)}{g(\phi(\varepsilon))} f(\varepsilon) d\varepsilon + f(\underline{\varepsilon})(\rho_B + x_G^*) = c_B'(x_B^*). \tag{8}$$

We see that if $r < 1$, this tends to amplify investments in boys, for two reasons. First, a given increment in investment pushes boys more quickly up the distribution of girls, and second, there is an incentive to invest in order to increase the probability of match taking place at all, since there is discontinuous payoff loss from not being matched at $\underline{\varepsilon}$.

Similarly, the first order condition for investment in girls is given by

$$\int_0^{\bar{\eta}} \left(\phi^{-1}\right)'(\eta) g(\eta) d\eta = r \int_0^{\bar{\eta}} \frac{g(\eta)}{f(\phi^{-1}(\eta))} g(\eta) d\eta = c'(x_G^*). \tag{9}$$

Notice here that the role of $r < 1$ is to reduce investment incentives, since an increment in investment pushes a girl more slowly up the distribution of boy qualities. Furthermore, the term corresponding to $f(\underline{\varepsilon})(\rho_B + x_G^*)$ is missing. That is, there is no reason to invest in order to increase the match probability since all girls get matched for sure, and the only reason to invest arises from the consequent improvement in match quality.

We shall assume henceforth that F and G have the same distributions, i.e. the idiosyncratic component of match value is identically distributed in the two sexes. Our first result is the investments are efficient when $r = 1$, since in this case $\phi(\varepsilon) = \varepsilon$ when the distributions are equal. Thus the first term in (8) equals one, and the second term is absent, so that $c_B'(x_B^*) = 1$, and similarly $c_G'(x_G^*) = 1$. Thus if the social planner can ensure a balanced sex ratio, investments need not be regulated since they will coincide with the first best level. Intuitively, when $r = 1$ and $F = G$, it is as though each person is matched with himself, and this provides incentives for efficient investment.

Since the integrals in (8) and (9) are quite complex, we now specialize to the case where $f = g$ and both are uniform on $[0, \bar{\varepsilon}]$. The equilibrium investment levels are defined by

$$c_B'(x_B^*) = 1 + \frac{\rho_B + x_G^*}{\bar{\varepsilon}} > 1.$$

[22] We assume that the second order condition is satisfied – see the appendix for details.

$$c'_G(x^*_G) = r.$$

Thus we see that there are excessive investment in boys relative to what the social planner would choose – the marginal cost of investment exceeds one, while efficiency at the investment stage requires $c'_B(x^*_B) = r < 1$. There are insufficient investments in girls, since $c'_G(x^*_G) = r$ rather than the efficient level, one.

Our results are of interest given evidence suggesting that parents in India favour boys, by devoting greater care and resources to them. This maybe due to the fact that with gender biased preferences, parents are more altruistic towards their boys than their girls. Our analysis shows that this gender bias in investments may be intensified by marriage market considerations when the sex ratio becomes biased. Paradoxically, even though the position of girls improves in the marriage market, and raises their value, parents may also reduce educational investments in them, or save less for their dowries.

Our results are relevant in the context of empirical work by Wei and Zhang (2009), arguing that the high savings rate in China is due to the sex ratio imbalance. They argue that parents of boys feel compelled to invest more, raising the overall savings rate. Our analysis shows that while this is true, this is counterbalanced by the reduced investment incentive for parents of girls. If we assume that the costs of investment are quadratic, aggregate investment in the economy, $X^{**}(r)$, will be proportional to the weighted sum of the right hand side of the optimality conditions, i.e.

$$X^{**}(r) = \frac{r}{1+r} x^*_G + \frac{1}{1+r} x^*_B \propto \frac{1+r^2}{1+r} + \frac{\rho_B + x^*_G}{\bar{\varepsilon}(1+r)}.$$

Note that the first term, $\frac{1+r^2}{1+r}$, is increasing in r, while the derivative of the second term is ambiguous, since both the numerator and denominator are increasing in r. However, if $f(\underline{\varepsilon})$ is sufficiently large, then parents will invest a large amount in boys in order to improve the probability that they are matched at all, and this will raise overall investments and savings, as Wei and Zhang suggest.

Determination of the sex ratio

For $r \leq 1$, define the payoffs to boys and girls, given equilibrium investments:

$$\tilde{U}(r) = u_B + r[\rho_B + \mathbf{E}(\eta) + x^*_G] - c_B(x^*_B),$$

$$\tilde{V}(r) = u_G + \rho_G + \mathbf{E}(\varepsilon | \varepsilon \geq \underline{\varepsilon})] + x^*_B - c_B(x^*_G).$$

We see therefore that the payoff difference between boys and girls increases with r, since x^*_B is decreasing in r and x^*_G is increasing in r. Thus, if an equilibrium exists, it will be unique. The proposition below shows that an equilibrium will exist provided that either the density function $f(.)$ is continuous at zero, or if $f(0)$ is small enough, so that the discontinuity at zero is small. In the uniform case, existence is ensured provided that the dispersion in idiosyncratic values is sufficiently large, i.e. if $\bar{\varepsilon}$ is large enough.

Proposition 3 *Assume that the density function of match values for boys, $f(.)$ is continuous at zero, or that $f(0) < \delta$, where $\delta > 0$ is a function of all the parameters. Equilibrium exists and is unique in an economy where parents choose the gender of their child and how much to invest. If match values are identically and uniformly distributed across the sexes, such an equilibrium is characterized by overinvestment in boys and under-investment in girls, relative to the welfare optimal level, and the sex ratio r^* is inefficiently low. If a social planner can ensure a balanced sex ratio, then equilibrium investments will be efficient if match values are identically distributed for the two sexes.*

We therefore see that parental investment decisions partially counteract the sex ratio implications of gender biased preferences. The parents of boys invest more, and those of girls invest less, and this raises the payoff to having a girl and reduces the payoff from having a boy. Thus the sex ratio is more balanced than it would be in the absence of parental investments, paralleling our results in the previous section, where the change in intra-household allocations reduces the sex ratio imbalance. One important difference is that unlike transfers, the investment decisions have direct efficiency consequences, and are distorted relative to what the social planner would want. As we have seen, if the social planner could ensure a balanced sex ratio, then investment decisions would also be efficient, so that overall efficiency is ensured.

4 Heterogeneity

What are the implications of the population belonging to distinct groups, who are ex ante heterogeneous, e.g. they belong to different classes/ castes or linguistic groups? One may distinguish two distinct cases, horizontal differentiation and vertical differentiation. With vertical differentiation, groups are hierarchically ordered, and an individual prefers a partner of higher status to one of lower status, independent of the individual's own status. Class or caste are a possible examples. Horizontal differentiation occurs when an individual prefers a partner of his/her own group – linguistic, regional or religious identity are cases in point. These two cases turn out to have very different implications.

To model horizontal heterogeneity, let there be two groups or regions, 1 and 2. Let ρ^H be the payoff to an individual from matching with someone from the same region, and ρ^L be the payoff from matching with someone from a different region. Suppose that gender preferences are the same across regions. The equilibrium sex ratio will be the same in both regions, and in a stable match, there will be no inter-regional marriages. Now suppose that region 1 has large gender bias, while region 2 has no gender bias. In the absence of inter-regional marriages, the sex ratio in region 1 will be $r_1^* < 1$. In the absence of population growth, the sex ratio in region 2 will be 1. A male of quality $\underline{\varepsilon_1} = F(1 - r_1^*)$ is available to any woman in region 2, and the woman with the greatest incentive to make this match is the one with the lowest quality, $\eta = 0$. Her payoff from making this match is $\underline{\varepsilon}_1 + \rho^L$, while her payoff from matching within her own region is ρ^H. Thus the imbalance in region 1 must be large enough to offset the payoff difference $\rho^H - \rho^L$, before any inter-regional marriages take place.[23] If there is population growth, then there will be an excess supply of girls in region 2, and those of the lowest quality will marry the lowest quality boys from region 1. However, inter-regional marriages yield small gains in utility, since both parties to the marriage get a payoff only of ρ^L, and therefore, the effects of ex ante selection decisions will be small. This discussion has empirical relevance in the context of the last column of Table 1, which shows the difference between actual and required number of boys across the regions of India. The surplus in the North West (10.7 boys per 100 girls) is counterbalanced by the deficit in the South (-11.2), the East (-8.8) and the West (-8.0). Given the large cultural differences between the South and the North-West, there is likely to be limited gains from trade, but there may be more possibilities with regard to the East or West.

Vertical differentiation is qualitatively different, since inter-group marriages will have large utility consequences for one party. To model this, assume that there are n classes (or castes), where 1 indexes the highest class and n the lowest. Let μ_i be the measure of class i, which is assumed to be increasing with i, so that we have a pyramidal society. Assume, for simplicity, that the value from being matched does not vary across boys and girls, but does depend upon the status of the partner. Let ρ^i be the value from being matched to a partner of class i, where $i \in \{1, 2, ..., n\}$. Assume also that the preference parameters are identical across the two classes, and satisfy $u_B - u_G > 2c$ and $u_B + \rho^{i+1} < u_G + \rho^i$, where $\rho^{n+1} \equiv 0$, since n is the lowest class.[24] For simplicity, we assume that the idiosyncratic component of match value is absent. This allows us to solve for an equilibrium recursively, from the upper class to the lower class. For the highest class, the equilibrium sex ratio, r_1^*, is less than 1 and satisfies the indifference condition

[23] This assumes non-transferable utility. With transferable utility, the condition for inter-regional marriage is more stringent – $\underline{\varepsilon}_1$ must be greater than $2(\rho^H - \rho^L)$.

[24] We may allow our utility parameters (u_B, u_G and c) to be indexed by class – the equations that follow also apply with the appropriate indexation. However, some of the qualitative results – the comparisions across classes – depend on the parameters not being too different across classes.

$$u_B + r_1^* \rho^1 + (1 - r_1^*)\rho^2 - 2c = u_G + \rho^1.$$

Now suppose that the sex ratio has been determined in all classes $j \leq i$, and that the sex ratio in class i is $r_i^* \leq 1$. A measure $\frac{1-r_i^*}{1+r_i^*}\mu_i$ of class i boys are available, and if the sex ratio in class $i+1$ is r_{i+1}, the measure of girls in this class is $\frac{r_{i+1}}{1+r_{i+1}}\mu_{i+1}$, and each such girl has a probability $p^{i+1}(r_i, r_{i+1}^*) = \frac{(1+r_{i+1})(1-r_i^*)\mu_i}{r_{i+1}(1+r_i^*)\mu_{i+1}}$ of marrying a boy from the higher class. This leaves a measure $\left[\frac{r_{i+1}}{1+r_{i+1}}\mu_{i+1} - \frac{1-r_i^*}{1+r_i^*}\mu_i\right]$ of class $i+1$ girls who are matched with a measure $\frac{\mu_{i+1}}{1+r_{i+1}}$ of class $i+1$ boys, and let $\tilde{r}_{i+1}(r_i, r_{i+1}^*)$ denote the ratio of these two measures. The payoff to boys of class $i+1$ is given by

$$U^{i+1}(r_{i+1}, r_i^*) = u_B + \tilde{r}_{i+1}(r_i, r_{i+1}^*)\rho^{i+1} + [1 - \tilde{r}_{i+1}(r_i, r_{i+1}^*)]\rho^{i+2}.$$

The payoff to lower class girls is given by

$$V^{i+1}(r_{i+1}, r_i^*) = \begin{cases} u_G + p^{i+1}(r_i, r_{i+1}^*)\rho^i + [1 - p^{i+1}(r_i, r_{i+1}^*)]\rho^{i+1} \text{ if } \tilde{r}_{i+1} \leq 1 \\ u_G + p^{i+1}(r_i, r_{i+1}^*)\rho^i + [1 - p^{i+1}(r_i, r_{i+1}^*)][\rho^{i+2} + \frac{1}{\tilde{r}_{i+1}}(\rho^{i+1} - \rho^{i+2})] \text{ if } \tilde{r}_{i+1} \geq 1 \end{cases}.$$

The equilibrium sex ratio r_{i+1}^*, is determined as follows. If $|U^{i+1}(1, r_i^*) - V^{i+1}(1, r_i^*)|$ is less than $2c$, then $r_{i+1}^* = 1$. Otherwise, r_{i+1}^* is such that $\left|U^{i+1}(r_{i+1}^*, r_1^*) - V^{I+1}(r_{i+1}^*, r_1^*)\right| = 2c$. Note that $r_{i+1}^* \leq 1$ if μ_{i+1} is sufficiently large relative to μ_i.

We have therefore solved recursively for the equilibrium sex ratio, starting from the highest class. Note that $r_2^* > r_1^*$, that is the sex ratio is more favorable to girls in the second class as compared to the highest class. This arises since the imbalance in the sex ratio amongst the topmost class increases the payoff to lower class girls (since they can marry up), while reducing the payoff to lower class boys (for any value of r_2, the probability that a lower class boy gets a partner increases with r_1^*). More generally, r_{i+1}^* is decreasing in r_i^*. Now suppose that $\rho^i - \rho^{i+1}$ is constant for all $i < n$, so that the increment from marrying up is constant across classes. Since $r_2^* > r_1^*$, this implies that the incentive to have a girl is weaker in class 3 as compared to class 2, so that $r_3^* < r_2^*$, so one has an oscillating pattern of the equilibrium sex ratio. Finally, if the cost of not marrying is large relative to any payoff gain from marrying up, i.e. if $\rho^n \gg \rho^{n-1} - \rho^n$, then the incentive to have a girl is strong in the lowest class since boys there cannot marry down. Thus r_n^* will be larger than the sex ratio in other classes.

The basic finding, that incentives for having boys are higher in the upper classes, is relevant for empirical work, suggesting that one should observe more male biased sex ratios in the higher classes or castes, as compared to the lower ones. This is consistent with census data from India – the sex ratio in the lowest castes (the scheduled castes and scheduled tribes) are more female friendly than in the rest of the population. They are also consistent with data from the 1931 Indian census, the last census for which detailed caste based sex ratios at all levels are available. More recently, Portner (2009) uses survey data on the fertility decisions of married women from India's National Family Health Surveys in order to estimate the hazard rate for sex selective abortions. He finds that selection is restricted to women with eight years of schooling. Since education is highly correlated with caste and economic status, this is consistent with our theoretical predictions, although education could also directly affect the access to selection technologies.

From a welfare point of view, note that parental sex selection reduces ex ante expected utility in the upper most class, under similar assumptions as in our simple model (i.e. if $u_G - u_B + 2c + 2(\rho^1 - \rho^2) > 0$). More interesting is the effect on the lower classes, since selection in the class above raises the payoffs to girls, while lowering the payoff to boys. A benchmark case is when $r_i^* = 1$, in some lower class $i > 1$, so that there is no selection in this class. If $2\rho^i > \rho^{i+1} + \rho^{i-1}$, then the benefit to a girl who marries up is less than the cost to the consequent lower class boy who fails to find a partner in class i. So sex selection reduces welfare also in the lower class. Suppose now that $r_i^* < 1$. In this case, negative welfare effects are aggravated, since selection in the lower class reduces welfare, as in the simple model. We conclude that sex selection reduces welfare also in the lower classes, on the assumption that parameter values are such that there is no selection for girls in these classes. [25]

Our results here are different from those obtained by Edlund (1999), who examines the consequence of sex selection in finite society where every individual is strictly ordered by rank, rank being endowed ex ante. She finds that if sex selection is perfect, then the sex ratio will be balanced, with boys being chosen by high ranked individuals. Imbalances in the sex ratio can only arise with noisy selection, where parents can only choose boys (or girls) with some probability $p \in (0.5, 1)$, and this imbalance increases with son preference. In contrast, we find that aggregate sex ratios can be unbalanced even when selection is perfect and costless ($c = 0$), due to the fact that each class has a large number of ex ante homogeneous agents. We are also able to analyze the welfare implications of selection, and unbalanced sex ratios in this context.

[25] If parameter values are such that there is selection for girls, then it is possible for sex selection to be welfare increasing for the lower classes.

5 Fertility, family composition and selection

Parents normally have more than one child, and their relative preferences between a boy and girl are likely to depend upon the gender composition of their existing children. The desire to have grandchildren is also likely to display an element of diminishing returns. To model these considerations, consider a family with m boys and f girls. Abstracting from marriage market considerations, let the utility to the parents be given by $U(m, f)$, where $U(.)$ is strictly concave. In particular, assume that for any given family size n, $U(m+1, n-m-1) - U(m, n-m)$ is strictly decreasing in m. This assumption implies that the incentive to select for boys will be greater in families where the first (or first few children) are girls than where the first child (or children) are boys. This is consistent with the findings of Jha et al. (2006), who use a survey of 1.1 million Indian households. They find that the sex ratio is more biased against girls if the first or first two children are girls, than if they are boys.

Assume, for simplicity, that family size is exogenously given at $n > 1$. Many demographers argue that parents in East/South Asia have a strong preference for at least one boy, and that this preference underlies gender based stopping rules, such stopping after the first boy. To model this, let us assume that

$$U(1, n-1) - U(0, n) > 2c,$$

so that the marginal utility of a boy exceeds that of a girl when you already have $n-1$ girls by a margin that is larger than c, abstracting from considerations of reproductive value. Assume also that

$$|U(m+1, n-m-1) - U(m, n-m)| < 2c \text{ if } m > 0.$$

This implies that if a family has one or more boys, then it does not have an incentive to select for boy (abstracting from considerations of reproductive value). Nor does it have any incentive to select for girls, at any point.

We now turn to marriage market considerations. Let $\rho(\ell)$ be the value to the parent from having ℓ children matched, where ρ is increasing and strictly concave. Let utility be perfectly transferable, and let $t(r)$ denote the transfer from boys to girls, where $t(1) = 0$ and $t(r)$ is continuous and decreasing in r. Suppose that the sex ratio is sufficiently close to 1 so that the reproductive value of a family of any composition is approximately equal to $\rho(n)$, independent of family gender composition, and $t(r)$ is close to zero. Under these assumptions, it follows that the optimal strategy is to not select, only at the last birth, and if all $n-1$ previous births have been girls. The sex ratio corresponding to families following this strategy is given by $\check{r}(n)$:

$$\check{r}(n)=\frac{(0.5)^{n-1}\left\{\frac{n-1}{2n}\right\}+\left[1-(0.5)^{n-1}\right]}{(0.5)^{n-1}\left\{\frac{n+1}{2n}\right\}+\left[1-(0.5)^{n-1}\right]}. \tag{10}$$

As n increases, $\check{r}(n)$ tends to 1, since it becomes increasingly unlikely that all n draws result in a girl. We get the following table for values of $\check{r}(n)$.

Table 2

n	2	3	4	5	6
$\check{r}$	0.714	0.909	0.957	0.987	0.995

Table 2 shows that $\check{r}$ is very close to 1 (with only 5 missing women per 1000 male population) when $n = 6$. It declines as n falls, and the decline accelerates. By $n = 3$, there are 90 missing women, and at $n = 2$, there are almost 300 missing women. Thus, the existence of preferences of this sort gives rise to a positive relation between fertility and the sex ratio, and the claim that declines in family size – such as under the one child policy in China – have aggravated sex ratio imbalances, in the presence of selection.

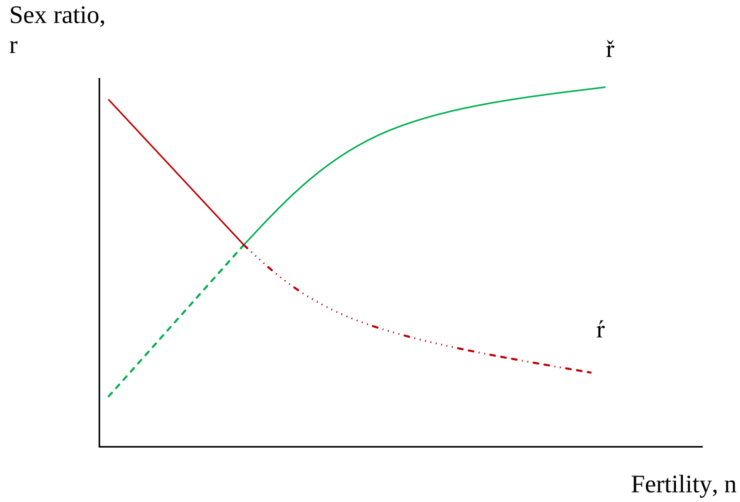
However, this analysis abstracts completely from considerations of the marriage market. As n declines, the sex ratio declines as well, so that reproductive value diverges considerably from $\rho(n)$, depending on family composition. Furthermore, if r declines, girls will be able to get a more favorable household allocation, and this will be internalized by the parents. We now take these factors into account. Suppose that $r \leq 1$, so that girls are matched for sure, while each boy is matched with independent probability r. The total payoff from selection at the last birth is given by

$$U(1,n-1)+r[\rho(n)+(n-2)t(r)]+(1-r)[\rho(n-1)+(n-1)t(r)]-2c.$$

That is, with probability r the boy gets matched, and the total payoff is $\rho(n)$ plus the transfer corresponding to $n-2$ girls (since the negative transfer of the boys offsets that of one of the girls). With probability r, the payoff is $\rho(n-1)$ plus $n-1$ transfers. Since the payoff from keeping a girl is given by $U(0,n)+\rho(n)+nt(r)$, the payoff gain from selection is given by

$$[U(1,n-1)-U(0,n)]-2t(r))-(1-r)[\rho(n)-\rho(n-1)+t(r)]-2c. \tag{11}$$

Let $\mathring{r}(n)$ be the value of r such that (11) equals zero. Since the expression in (11) is increasing in r, selection is optimal at the last birth for $r \geq \mathring{r}(n)$ and non-selection is optimal if this inequality is reversed. Thus the equilibrium sex ratio $r^*(n)$ is given by



$$r^*(n) = \max\{\mathring{r}(n), \check{r}(n)\}.$$

Fig. 1 graphs the functions $\check{r}(n)$ and $\mathring{r}(n)$, where the equilibrium $r^*(n)$ is given by the higher of these two curves, and is depicted by an unbroken line. Since $\check{r}$ is an increasing function while $\mathring{r}$ is a decreasing function, there exists a critical value $\tilde{n}$ such that $r^* = \mathring{r}$ for $n \leq \tilde{n}$ and $r^* = \check{r}$ for $n > \tilde{n}$. That is, to the right of $\tilde{n}$, families select at the last child if all previous ones are girls, and this is optimal since the consequent sex ratio $\check{r}$ is such that (11) is strictly positive, given that $\check{r} > \mathring{r}$. To the left of $\tilde{n}$, if families select at the last child if all previous ones are girls, this will not be optimal – the consequent sex ratio $\check{r}$ is such that (11) is strictly negative, given that $\check{r} < \mathring{r}$. Thus only some families select, while others do not, and the sex ratio $\mathring{r}$ is such that both these yield the same payoff. This implies that the effect of family size on the sex ratio in not monotone. A fall in family size initially reduces the sex ratio, but further declines will tend to increase the sex ratio.

Consider now the implications of heterogeneity in family size in the population, with some families having n_1 children and others having n_2 children, $n_2 > n_1$. Suppose that n_1 and n_2 are both to the right of $\tilde{n}$. Then both types of families will select at the last child if all previous ones are boys, and the aggregate sex ratio will equal $\lambda\check{r}(n_1) + (1 - \lambda)\ \check{r}(n_2)$ where λ is the population weight of families with size n_1, and will therefore lie in the open interval $(\check{r}(n_1),\ \check{r}(n_2))$.The sex ratio will be more biased towards boys in smaller families, since they are more likely to exercise selection.

Now suppose that n_1 and n_2 are both small, i.e. less than $\tilde{n}$. The analysis here is quite different from the previous scenario. The aggregate sex ratio must lie in the *closed interval* $[\check{r}(n_2),\, \check{r}(n_1)]$ – there is a range of parameter values such that the sex ratio is exactly $\check{r}(n_2)$, and similarly, a range of parameter values such that it is exactly $\check{r}(n_1)$. Suppose that λ is small, so that a large fraction of the population has size n_2. In this case, if the indifference condition is satisfied for families of size n_2, the sex ratio within this group can be any number in the interval $[\mathring{r}(n_2), 1]$, where $\mathring{r}(n_2) < \check{r}(n_2)$. Thus we can have $(1-\lambda)\theta\mathring{r}(n_2) + \lambda = \check{r}(n_2)$, where $\theta \leq 1$ is the fraction of these families selecting, if λ is small, and at this sex ratio, the smaller families will not select. Similarly, if λ is large, then the sex ratio will be $\check{r}(n_1)$, where a fraction of of the smaller families will be selecting while the larger families all select. For intermediate values of λ, the sex ratio will lie in the interval $(\check{r}(n_2), \check{r}(n_1))$, where large families have a strict incentive to select and have sex ratio $\mathring{r}(n_2)$, while small families have no incentive to select and have sex ratio 1. Thus, larger families have a more male biased sex ratio than smaller families when n_1 and n_2 are both small, whereas the previous paragraph shows that smaller families have a more male biased sex ratio when both n_1 and n_2 are large.

Our analysis can be used to analyze the implications of the one-child policy in China. It has been argued that the one-child policy has aggravated sex selection in China – see, for example, Hesketh et al. (2006).[26] This argument is based purely on temporal and spatial coincidence between the policy and sex ratios. The policy was introduced in 1978, and the sex ratio has moved against girls since. However, this is about the time that new technologies for sex selection became available. Secondly, sex selection appears to be greater in urban areas, where the one-child policy is more rigorously enforced, than in rural areas, where enforcement is more lax. Here again, urban areas have superior medical facilities, so that selection may be easier than in rural areas. Furthermore, the urban areas are also richer than the poorer areas, and the ability of richer boys to marry down would imply that the incentive to select may be greater in urban areas, as our discussion in section 4 demonstrates. In consequence, it is hard to infer causality from these correlations.

Our analysis suggests that while the effect of fertility decline upon the sex ratio may be unambiguous when fertility is large, it may not make the sex ratio more male biased at low family sizes. Intuitively, when parents have many girls, the incentive to select for a boy is stronger, due to diminishing "marginal utility" for girls, and since the girls ensure grandchildren when $r < 1$.

[26] These arguments have been made mainly in medical journals, but more extreme versions of the same argument are very prevalent in the press. For example, Eric Baculinao of NBC News (Baculinao, 2004) writes: ‘The age-old bias for boys, combined with China’s draconian one-child policy imposed since 1980, has produced what Gu Baochang, a leading Chinese expert on family planning, described as "the largest, the highest, and the longest" gender imbalance in the world.’

6 Societies without generalized gender bias

Our analysis may also be applied to societies without generalized gender bias, such as the UK or the US, where sex selection could be used for family balancing reasons. In the UK, the Human Fertilization and Embryology Authority recommended against allowing sex selection for "social reasons" (including family balancing).[27] The American Society of Reproductive Medicine is more positive : "If flow cyclometry or other methods of preconception gender selection are found to be safe and effective, physicians should be free to offer preconception gender selection in clinical settings to couples who are seeking gender variety in their offspring..." (May 2001).

While there is unease in official circles with allowing sex selection, there is considerable evidence that many parents have a desire for gender balance within the family. US census data for 1980 and 1990 shows that women with two children are 6% more likely to have a third child if the children are of the same gender (Angrist and Evans, 1998). The probability of a third child is slightly greater (1-2%) if the two children are girls rather than boys. This suggests that gender balancing is a primary concern, but also that the sexes are not treated completely symmetrically. Dahl and Moretti (2008) present suggestive evidence that parents in the US, especially men, prefer boys to girls. [28]

To examine these issues, we adapt the model of gender preferences based on family composition. For simplicity, suppose that family size is fixed exogenously at two. Focus attention on the subsection of the population that is willing to select. To reflect preferences for gender balancing, assume that in this group, $U(1,1)-U(2,0) > 2c$ and $U(1,1) > U(0,2)$, but that this difference may or may not exceed $2c$. Thus we allow for the possibility that preferences are not completely symmetric across genders, i.e. there is an element of bias (our analysis obviously applies, with minor modification, if the bias is reversed).[29]

For reasons of space, we do not present analytical results here, and refer the reader to the discussion paper version of this paper. In the case where preferences are relatively symmetric, so that $U(1,1)-U(0,2)$ also exceeds $2c$, the overall equilibrium will be one where every family in the group that may select has one boy and one girl, and thus the overall sex

[27] The UK allows sex selection for genetic reasons, when there is the risk of gender specific genetic disorders.

[28] They find that women with first born daughters are less likely to marry, and also more likely to divorce if married, than women whose first born is a son. Interestingly, shot-gun marriage is more likely if the child *in utero* is a boy, and the mother has an ultrasound. They also find that if the first birth is a daughter, this increases the expected number of children. Abrevaya (2009) finds evidence of biased sex ratios in Asian families in the US.

[29] Asymmetries can also arise for technological reasons. Sperm separation techniques are currently more effective for selecting for girls than boys, so that the effective cost of selection could differ across the sexes. Our analysis would also apply if there were differences in the costs of selection rather than differences in gender specific utilities.

ratio will be balanced. In this case, there are no externalities associated with the selection decision, and allowing selection for family balancing raises welfare. On the other hand, if $U(1,1) - U(2,0) < 2c$, the equilibrium will be one where the sex ratio r^* is less than one. The equilibrium is inefficient and social welfare can be increased by moving towards a more balanced sex ratio. If the overall gains from family balancing are small relative to the cost of selection, then is efficient not to permit selection. However, if the overall gains are large, then it is efficient to encourage selection also by families whose first child is a girl, so that this balances the sex ratio.

7 Conclusions

This paper's main contribution is a model of the equilibrium sex ratio when parents can choose the gender of their child. This allows us to examine the welfare consequences of selection. If gender bias is large, parental choice results in too many boys, and reduces welfare. Conversely, if intrinsic gender bias is mild or absent, and the observed preference for boys is due to the excess supply of girls due to the marriage squeeze, selection may increase welfare. Our results are robust in many ways; they hold if household allocations or parental investments are influenced by the sex ratio, in a continuous way. We have also examined the effects of sex ratio imbalances on gender differences in parental investments in children. Our analysis of the effect of fertility and family size upon equilibrium sex ratios is relevant in the context of the decline in fertility in East/South Asia, especially China. We believe that the model provides a useful framework to examine a host of issues related to sex ratios.

8 Appendix

Proof of Proposition 1: We show that the global welfare optimum corresponds to $r = 1$ under assumption A1**.** At $r < 1$, the derivative of welfare is given by

$$W'(r)|_{r<1} = (u_G + \rho_G + 2c - u_B) + \left(1 - r + \frac{r}{\gamma}\right)(\rho_B + \mathbf{E}(\eta)) + \left(1 - \frac{1}{\gamma} - \frac{r}{\gamma^2}\right)\mathbf{E}(\eta|\eta \geq \underline{\eta}).$$

Since the first term in brackets is strictly positive, it suffices to show that the second and third terms is positive. Since $\mathbf{E}(\varepsilon|\varepsilon \geq \underline{\varepsilon})$ is bounded above by $\bar{\varepsilon}$, and $\underline{\varepsilon} \geq 0$, a sufficient condition for these to be positive is

$$\frac{(\rho_B + \mathbf{E}(\eta))}{\bar{\varepsilon}} \geq \frac{r + \gamma - \gamma^2}{\gamma\left(\gamma(1-r)+r\right)}.$$

Since the right hand side above is less than $\frac{1}{\gamma}$, the inequality is satisfied under A1.

Consider now the derivative at $r > 1$:

$$W'(r)|_{r>1} = (u_G + 2c - u_B - \rho_B) - \frac{1}{r}\left(\frac{1}{\gamma} + \frac{r}{\gamma^2} - 1\right)(\rho_G + \mathbf{E}(\varepsilon)) + \frac{1}{r}\left(1 - r + \frac{r}{\gamma}\right)\mathbf{E}(\eta|\eta \geq \underline{\eta}).$$

Since the first term in brackets is strictly negative, it suffices to show that the sum of the remaining terms is negative. This reduces to the condition

$$\frac{\rho_G + \mathbf{E}(\varepsilon)}{\mathbf{E}(\eta|\eta \geq \underline{\eta})} \geq \gamma\frac{\gamma(1-r)+r}{\gamma + r - \gamma^2} \tag{12}$$

A1 states that $\gamma + 1 > \gamma^2$, so the denominator on the right hand side of (12) is positive. The derivative of the right hand side of (12) with respect to r is negative, and so if the inequality is satisfied for $r = 1$, it is also satisfied for all larger values of r. Thus the critical condition is

$$\frac{\rho_G + \mathbf{E}(\varepsilon)}{\mathbf{E}(\eta|\eta \geq \underline{\eta})} \geq \frac{\gamma}{\gamma + 1 - \gamma^2},$$

which is ensured by A1.

Proofs relating to section 2:

We show first that $t^*(x)$ is decreasing in x. Differentiating (4) we obtain

$$\frac{dt^*}{dx} = \frac{\alpha'(x)(\rho - t^*) - \beta'(x)(\rho + \xi(t^*)}{(\alpha + i) + (\beta + i)\xi'(t^*)} < 0,$$

since α is decreasing in x and β is increasing.

To show that the match efficiency term is maximized at $x = 1$, define

$$M'(x) \equiv (1-\theta)\tilde{U}'(x) + \theta\tilde{V}'(x).$$

Differentiating the expressions for $\tilde{U}$ and $\tilde{V}$ and using condition (4):

$$M'(x) = \frac{\theta\beta'(\alpha + i) + (1-\theta)\alpha'(\beta + i)}{(\alpha + i)(\beta + i)^2}(\rho - t^*) + \left(\frac{\alpha\theta}{i(\alpha + i)}\xi'(t^*) - \frac{\beta(1-\theta)}{i(\beta + i)}\right)t^{*\prime}(x).$$

At $x = 1$, $\beta' = -\alpha'$, $\beta = \alpha$ and $\theta = \frac{1}{2}$, so the first term equals zero. Since $\xi'(0) = 1$, the second term is also zero.

Proof relating to section 3:

The second order condition for the optimality of x_B^* is

$$\frac{1}{r}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} \frac{1}{g^3(\phi(\varepsilon))}\left[g^2(\phi(\varepsilon))f'(\varepsilon)-\frac{1}{r}f^2(\varepsilon)g^{'}(\phi(\varepsilon))\right]d\varepsilon - f'(\underline{\varepsilon})(\rho_B+x_G^*)-c_B^{''}(x_B^*)<0.$$

We assume that this sufficient condition is satisfied. There is an open set of distributions such that this condition holds. If $f(.)$ and $g(.)$ are both uniform, the condition reduces to $-c_B^{''}(x_B^*)<0$, which follows from the strict convexity of the cost function. Thus if the distributions are close to being uniform,the condition will hold. Furthermore, if $r=1$ and $f=g$, then the condition also reduces to $-c_B^{''}(x_B^*)<0$ (the second term $f'(\underline{\varepsilon})(\rho_B+x_G^*)$ is absent in this case). A similar argument applies to the sufficient condition for girls, where the second term is absent.

Proof of proposition 3: Equation (9) shows that x_G^* is a continuous function of r for all $r\in[0,1]$. Equation (8) shows that x_B^* is a continuous function of r for all $r\in[0,1]$ as long as $f(.)$ is continuous at zero (since $f(.)$ is assumed to be continuous on its support). Thus the payoff difference between boys and girls, $\tilde{h}(r)=\tilde{U}(r)-\tilde{V}(r)-2c$, is a continuous function of r. If $\tilde{h}(1)\leq 0$, then $r=1$ is an equilibrium since we have assumed that there is weak son preference so that $\tilde{U}(1)-\tilde{V}(1)$ is non-negative. If $\tilde{h}(1)>0$, then since $\tilde{h}(0)=u_B-u_G-\rho_G-\bar{\varepsilon}-2c<0$, the intermediate value theorem ensures that there is a value $r\in(0,1)$ such that $\tilde{h}(r)=0$. If $f(\varepsilon)\to k>0$ as $\varepsilon\downarrow 0$, then equation (8) shows that x_B^* increases discontinuously as r changes from 1 to a value below one. The size of this jump is proportional to $f(0)$ since $\underline{\varepsilon}\to 0$ as $r\to 1$, and $f(.)$ is continuous on its support. Since $\tilde{h}(1)>0$, $\lim_{r\uparrow 1}\tilde{h}(r)$ will also be strictly positive as long as $f(0)$ is sufficiently small. The analysis in the text of the paper proves the welfare results, and that (quasi-symmetric) equilibrium is unique.

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