Sex Selection and Gender Balance*

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Abstract

Parents in many developing countries may prefer boys to girls, either due to intrinsic gender bias, or because of the *marriage squeeze* — girls find it harder to marry due to population growth and the age gap at marriage, and parents also value having grandchildren. With intrinsic gender bias, sex selection results in a male-biased sex ratio. This is socially inefficient, due to a congestion externality in the marriage market, and improvements in selection techniques aggravate the inefficiency. On the other hand, if intrinsic gender bias is absent, then sex selection may improve welfare in the presence of the marriage squeeze. These results are robust to allowing prices in the marriage market, if the market is subject to frictions. We also consider the implications of selection and the sex ratio for parental investments in their children. We extend the model to consider gender preferences which depend upon family composition, allowing us to examine the possible sex ratio effects of China's one-child policy, and the implications of choice in societies where family balancing considerations are paramount.

Keywords: gender bias, sex ratio, marriage market, sex selection, congestion externality, marriage squeeze.

JEL Categories: J12, J13, J16

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1 Introduction

In many parts of the world, parents exhibit *gender bias* — they prefer to have a boy child rather than a girl. 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. Indeed, the community of *hijras* (eunuchs), who traditionally make their living by extorting money on joyous occasions, demand substantially larger amounts when a boy is born as compared to when a girl is born. Gender bias is also reflected in male biased sex ratios, and the problem of "missing women" (Sen,1992), although the problem 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" — due to their practice of female infanticide. [1]

Modern medicine has aggravated the problem of unbalanced sex ratios by reducing the cost of choosing boys. The development and spread of amniocentesis and ultrasound screening in the early 1980s made foetal sex determination possible, permitting sex selective abortion.[2] Foetal sex determination for selective abortion is illegal in China and India, but the practice flourishes. Indeed, 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 (Chahnazarian, 1998). 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 at birth was 116.9, with some regions reporting ratios of 130-135. [3] 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 marriage market consequences of sex ratio imbalances of this magnitude are enormous. For example, it is estimated that 40-50 million Chinese men could 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

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

[2] Foetal blood tests now permit sex determination at six weeks.

[3] Oster (2005) argues that hepatitis B infection explains a part of the imbalance in the sex ratio, especially in China. However, there are large *increases* in the sex ratios in these countries across censuses, that are most plausibly due to the spread of sex selection techniques. For more direct evidence on the extent of sex selective abortions, see Arnold et al. (2002) and Jha et al. (2006).

endowed them with a strong desire for grandchildren. Can such biased 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 in a society with widespread gender bias? The standard response, from government agencies, international institutions and non-governmental organizations, is to deplore sex selection. In this view, gender bias reflects discriminatory preferences, that are based on ignorance and backwardness. Rather than allowing choice based on discriminatory preferences, the state has a duty to educate away such preferences, and in the meantime, constrain how they are exercised. This view is squarely paternalistic, in the sense that policy is not based upon the preferences of the citizens, but rather on those of enlightened agencies.

An alternative view, that is heard less often, is that allowing parental choice may in fact improve the position of girls. As girls become scarcer, their value will rise, and this will reduce realized gender bias and improve their position in society. Dharma Kumar (1983) was an early and trenchant proponent of this position. Indeed, she asks whether selective abortions are any worse than the neglect and infanticide of girl children. She goes on to argue that market forces will alleviate problems arising from discriminatory preferences. However, this view does not take into account possible externalities or market failure.

Indeed, it is notable that since Amartya Sen (1992) highlighted the question of "missing women", this question has attracted much attention from demographers and from empirical economists (e.g. Coale, 1991; 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. An exception is the work of Edlund (1999), who 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.[4] Following R.A. Fisher (1930), biologists have, of course, examined the question of equilibrium sex ratios; however, evolutionary models do not allow for any concerns apart from long run genetic representation, and also do not deal with welfare issues.

This paper proposes a simple economic model of parental choice in order to address these issues. We show that an imbalance in the sex ratio is an equilibrium consequence of gender biased preferences. At such an equilibrium, realized gender bias – 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, rather than raising the payoff to having a girl (although this may also happen to

[4] In section 3.0.1 we discuss sex selection in a class society, and in this context, we discuss Edlund's work in greater detail.

an extent). In consequence, parents who select for boys exert a congestion externality in the marriage market, so that parental sex selection reduces welfare, where welfare is evaluated in terms of the ex ante expected utility of the typical parent. Technological improvements in selection, such as ultrasound or *in vitro* fertilization, will worsen the sex ratio and reduce welfare.

Our conclusions are different if intrinsic gender bias is absent (or relatively mild), and if the observed preference for boys arises endonenously, 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 market at a balanced sex ratio, due population growth and the age gap at marriage between boys and girls. Indeed, many demographers (e.g. 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). In other words, they suggest that the marriage squeeze has made girl children less attractive to parents even in regions of India where girls have traditionally been valued. If population growth causes excess supply, and there is little or no intrinsic gender bias, then sex selection may improve welfare. Here again, we find that if the equilibrium marriage market sex ratio is biased towards girls, welfare can be raised by making the marriage market more balanced. However, the evidence suggests that sex selection appears to be taking place in regions with an effective excess supply of boys, and that it is therefore welfare reducing.

These negative social consequences arise from the fact that marriage markets without appropriate prices do not ensure efficiency. However, our conclusions are robust to allowing for prices, provided that markets are not assumed to be Walrasian. A frictional marriage market with prices produces results that are qualitatively similar to those in our simple model without prices. In particular, with 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.

We also extend our model to consider a variety of other issues. These include the effects of China's one-child policy on the sex ratio, the effect of exogenous changes in the sex ratio (due to hepatitis B infection (Oster, 2005)) when there is a behavioral response, and upon possible class differences in sex selection behavior.

Our model can also be extended to consider the implications of sex selection is societies without widespread gender bias, where family balancing is a primary consideration. Recent technological developments have made this possible, by allowing sex selection with low psychological costs. *In vitro* fertilization allows control over the sex of the embryo, thereby reducing the psychological and financial costs of sex selection – essentially, it comes for free for those undergoing fertility treatment. More experimental are the techniques for preconception gender selection, through the separation of X-bearing and Y-bearing sperm. While preconception gender selection is not yet established, it is very much on the horizon. Indeed, the American Society for Reproductive Medicine has argued that parents should be allowed these techniques, when feasible, for family balancing reasons. However, many developed countries such as the UK prohibit the use of gender selection for social reasons such as family balancing. Our model shows that while allowing sex selection for family balancing may improve individual utility, a congestion externality may similarly arise if preferences or not fully symmetric between the sexes (or if the costs of selection vary depending on the sex). Thus society must ensure that incentives are in place to produce outcomes that are gender balanced at the aggregate level.

The layout of the remainder of this paper is as follows. Section 2 sets out our basic model of parental choice, and the marriage market consequences of these decisions. Section 3 develops extensions of this model to consider ex ante heterogeneity, due to class or social status, and of factors that bias the sex ratio naturally, such as Hepatitis B. Section 4 considers how gender specific parental investments interact with the sex ratio. Section 5 allows for bride prices, in a Walrasian as well as frictional matching setting. Section 6 considers the implications of having more than one child. With gender biased preferences, it develops empirical implications on the pattern of selection, and on China's one-child policy. It also analyzes the implications of preferences for family balancing, in the absence of generalized gender bias. The final section concludes.

2 A Simple Model

The standard biological model of the sex ratio dates back 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 an equilibrium sex ratio that is balanced. In addition, in equilibrium, there is no gender bias – parents are equally happy when a girl is born as when a boy is.

Human societies have been transformed enormously from the hunter-gatherer societies where evolutionary preferences have been shaped. Increased life expectancy means that 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. The reforms raised the returns to cash crops such as tea and orchard fruit. While tea uses mainly female labor, orchards are usually tended by men. 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 section 4. 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. Without loss of generality, the von-Neumann Morgenstern utilities may be parametrized 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 ε has a continuous strictly increasing distribution $F(.)$ on support $[0, \bar{\varepsilon}]$. That is, any girl has a payoff ρ_G from marriage, and the term ε reflects the partner specific quality.[5] Similarly, all girls are ex ante identical, and her realized quality equals $\rho_B + \eta$. We shall assume that η has a continuous strictly increasing distribution, $G(.)$ on support $[0, \bar{\eta}]$, and has the same mean as ε, so that differences between ρ_B and ρ_G capture systematic differences in match values between the sexes. We shall assume that $u_B \geq u_G$ – 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 and similarly, a married boy is always preferred to a single girl, i.e. $u_B < u_G + \rho_G$, and $u_G < u_B + \rho_B$. 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

[5] That is, we are assuming that when individual i marries j, the payoff to i equals the quality of j. This assumption is standard in the literature, see for example, Burdett and Coles (1997).

way that their offspring do.

We now turn to supply and demand in the marriage market. This depends not only on the sex ratio but also upon population growth. 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 in a situation of population growth. For any positive age gap, population growth implies that the each cohort of men is matched with a larger cohort of women, giving rise to the *marriage squeeze.* The effective excess supply of women weakens their position on the marriage market. Indeed, demographers (e.g. 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 population, and let $\bar{r}$ be the sex ratio at birth (of girls relative to boys). Let τ be the age gap at marriage, assumed for simplicity to be exogenous. To simplify notation, let $\gamma = (1+g)^{\tau}$.Thus the ratio of women to men in the marriage market is related to the sex ratio at birth by the equation $r = \frac{\bar{r}}{\gamma}$. For expositional simplicity, we shall assume positive growth, so that $\gamma \geq 1$.[6]

We are now in a position to consider matching in the marriage market. First, we consider perfect matching, i.e. without any frictions. We require matchings to be measure preserving, and *stable,* in the sense of Gale and Shapley (1962). 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 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.

In our present 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 η, then

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

[6]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. From our analysis, it will be straightforward to see the implications of γ being less than one.

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.

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

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

That is, a boy has probability r of finding a match, and ex ante, before his own quality is realized, the match quality of his partner is a random draw from the set of all girls. Similarly, the ex ante expected utility of having a girl is now 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.[7] The sex ratio in the marriage market is given by the rate of growth of population , γ. Thus the payoff difference between having a boy and having a girl is given by

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

Thus, if there is positive population growth, 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 $\frac{1}{\gamma}$.

We now turn to the case where the cost of sex selections is sufficiently small that it will be exercised. Consider first the case of ex post selection, e.g. via sex selective abortions. Assume that once the mother becomes pregnant, she can observe the sex of foetus, and can subsequently pay a cost c to have an abortion and conceive another child. In this event, she has another independent draw, where the probability of a boy is one-half. Once again, if the parents are unsatisfied with the outcome of the new draw, they can again pay a cost of

[7] The natural sex ratio at birth is about 0.95; however, boys have higher mortality than girls. 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.

c and try again, and so on. Suppose that the sex of the foetus is female, so that the value of this option is $V(r)$. 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, c. So aborting the foetus and trying again is optimal if

$$U(r) - V(r)\} \geq 2c, \tag{1}$$

while accepting the girl child is optimal if the above 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 $\frac{1}{2}\{U(r)+V(r)\}$. It is easy to see that 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.[8]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 also easily extended to the case of imperfect ex ante selection technologies, such as sperm selection. If the technology costs c and produces a boy with probability $p > 0.5$, then the relevant cost is $\frac{2c}{2p-1}$ rather than $2c$ (as on the right hand side of equation (1)).

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:

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

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

[8]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.

$$[u_B + \rho_B + \mathbf{E}(\eta|\eta \geq \underline{\eta})] - [u_G + \frac{1}{r^*}(\rho + \mathbf{E}(\boldsymbol{\varepsilon}))] = 2c.$$

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 (2) 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. In this case, the equilibrium sex ratio r^* solves the equation

$$[u_B + r^*(\rho_B + \mathbf{E}(\eta)] - [u_G + \rho + \mathbf{E}(\varepsilon|\varepsilon \geq \underline{\varepsilon})] = 2c$$

To summarize: in the presence of population growth, 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. In either case, it is worth noting that at an interior equilibrium, the equilibrium marriage market sex ratio r^* does not depend upon the rate of population growth, γ. This is clear from the indifference condition (2) – neither $U(r)$ nor $V(r)$ depend upon γ.[9]

2.1 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 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?[11] Even if society is able to prevent sex selective abortions, it cannot ensure that the unwanted girls are loved and taken care of. In addition, we must note that the newer ex

[9] If we are not at an interior equilibrium (e.g. when there is no gender bias and when γ is small), then this is not true since $r = \gamma$

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

[11] Sex selective abortions are illegal in India and China; however, since both ultrasound and abortion are legal, it is hard to see how such a law can be enforced.

ante selection technologies are less open to these absolutist moral objections. In the present 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 in this society. Thus welfare, as a function of the sex ratio r, is given by

$$W(r) = \frac{1}{1+\bar{r}}U(r) + \frac{\bar{r}}{1+\bar{r}}V(r) - c\frac{1-\bar{r}}{1+\bar{r}}. \tag{3}$$

The first two terms are straightforward – a proportion $\frac{1}{1+\bar{r}}$ of parents have boys, and get utility $U(r)$, while the remainder have girls and utility $V(r)$. To account for the total cost associated with trying again for a boy, suppose that a measure λ of those parents who have girls at the first attempt keep trying until they get a boy. The expected cost associated with such a policy is given by the infinite summation $c + \frac{c}{2} + \frac{c}{4} + ..$, yielding $2c$. λ must equal $\frac{1-\bar{r}}{2(1+\bar{r})}$ in order to have the sex ratio at birth equal to $\bar{r}$.

Suppose now that the social planner can choose the level of r in order to maximize this welfare function – we shall see shortly what instruments might work in this context. The derivative of welfare with respect to r equals

$$W'(r) = \frac{[V(r) + 2c - U(r)] + (1+\bar{r})[U'(r) + \bar{r}V'(r)]}{\gamma(1+\bar{r})^2}. \tag{4}$$

Note that $U(r)$ and $V(r)$ are differentiable everywhere except at $r = 1$, when there is a switch in the marriage market from boys being rationed to girls being rationed. At this point, right and left hand derivatives exist. The derivatives are given by

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

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

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 the average quality of males who are matched is reduced; however, our assumptions on preferences, that the idiosyncratic component of match quality is small relative to ρ_B, imply that 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 than the negative effect on males.

Consider the derivative of welfare with respect to r, (4) evaluated at the equilibrium r^*. The first term in the numerator must equal zero, since the indifference condition (2) 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.

One can go further than this, and 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 [12]

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

Our results show that gender biased preferences that result in excessive males in the marriage market result in an inefficient outcome. The intuition for this inefficiency is as follows. Consider an equilibrium $r^* < 1$, and a parent who is choosing to select 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^*. Thus welfare is reduced by parental choice, the exercise of which moves the sex ratio towards imbalance. Intuitively, at the equilibrium sex ratio, a parent is indifferent between having a girl and trying again. 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 exercise choice. However, by not selecting, she exerts a positive externality, since an additional boy will be matched in the marriage market.

While selection reduces welfare when it causes an imbalance in the marriage market, it may have 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

[12] 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.

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.

We now consider the implications of changes in c upon equilibrium welfare, at an interior equilibrium where the basic indifference condition (2) is satisfied. Let $W^*(c)$ denote equilibrium welfare as a function of c, i.e.

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

Since it is optimal at r^* for a parent to accept the child that nature deals her, without trying again, this can be written as

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

From the indifference condition at r^*, that the difference between $U(.)$ and $V(.)$ equals $2c$, this can be re-written as

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

From the indifference condition that determines r^*,

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

Thus, the effect of welfare is given by

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

Since $V'(r) < 0$ and $U'(r) > 0$ 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 is unbalanced. 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 preferences are gender biased ($u_B+\rho_B > u_G+\rho_G+2c$), sex selection biases the equilibrium sex ratio, and results in a socially inefficient outcome, with too many boys.*

If the marriage market imbalance is due to population growth and the age gap at marriage, and there is no gender bias, then sex selection increases welfare, and is insufficient at the equilibrium, since there are too many girls in 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 has an excess of boys, but raises welfare if there are too many girls, due to population growth.

Proof. See preceding discussion. The appendix provides a proof of the global welfare optimality of $r = 1$. ■

2.2 Empirical Evidence

This proposition implies that the answer to question, is sex selection welfare reducing or welfare enhancing, is an empirical one. In this Chinese context, the empirical evidence is clear-cut. The decline in fertility due to the one-child policy means that cohort sizes have been declining since the 1980s. For example, a one-percent sample of the Chinese 2000 census shows that total births to Han Chinese fell from 176045 in the year 1991 to 107240 in the year 1999. This is quite a dramatic decline and even if there are questions as to the full representativeness of this sample, it shows that in China, there is a *reverse marriage squeeze.* That is, the age gap at marriage implies that there is an excess supply of men due to declining cohort sizes. Our model therefore implies that welfare optimality requires selection for girls. But as the same data shows, the sex ratio at birth is significantly biased towards boys – between the years 1991 and 1999, the sex ratio in the same group lies in the range 0.81 to 0.87. Thus, the conclusion that sex selection is severely welfare reducing is hard to escape.

The Indian case is more complex, since there is significant population growth and cohort sizes appear to be increasing. While we do not have a similar sample from the census, we may proceed by making some plausible assumptions. If we assume that the age gap at marriage is 5 years, and that the cohort sizes increase at 1% per annum, then $\gamma \simeq 0.05$. Thus a sex ratio of approximately 0.95 appears optimal from the point of ensuring a balanced marriage market. This figure needs to be qualified by controlling for differences in age-specific mortality between the sexes, but this adjustment turns out to be minor. Anderson and Ray (2009) show that age specific mortality is higher for girls than for boys. Using table 2 of their paper, one may conclude that higher mortality for girls results in a deficit of 2.6 girls relative to boys, per 1000, i.e. a difference of 0.0026 percentage points. Since the natural sex ratio at birth in India appears to be around 1.06 (Coale (1991) uses 1.059 while Anderson and Ray use the range 1.059 to 1.066), this suggests that the natural excess supply of males (due to the higher sex ratio at birth) is almost but not completely offset by the marriage squeeze effect.

However, when considers the data at regional level, we find that there are significant differences across regions. Figures from the 2001 census for the sex ratio in the age group 0-6 in the four main regions of India show that in the South and the East of India, the sex ratio is in the normal range, i.e. around 0.95. In the West and North, the sex ratio is much lower, around 0.91. In two states, Punjab and Haryana, the figure is substantially lower, at 0.80 and 0.82 respectively. Thus, sex selection appears to be taking place in regions where the $r < 1$, and from our proposition, appears to be welfare reducing.

In the light of this evidence, it appears that sex selection has adverse social consequences, suggesting that current policy banning sex selective abortions (in China and India) may be well motivated. However, a ban seems unworkable, since it is impossible to verify that a sex selective abortion has indeed taken place. An alternative policy is to increase the value of girls while reducing that of boys, by possibly taxing boys and making transfers to girls. This could be implemented, for instance, via differential school fees.

At this point, one may ask, are recent increases in the sex ratio in East and South Asia equilibrium phenomena, or do they reflect incorrect expectations on the part of parents? After all, parents must make choices today based on the anticipated sex ratio in the future. While learning models suggest that societies will be able to learn rational expectations equilibria in stable environments, recent technological developments have been so rapid that one cannot assume that behavior necessarily reflects equilibrium. expectational errors that result in an over-reaction of the sex ratio, the adverse welfare effects of selection are aggravated. Our point has been to demonstrate that negative welfare effects arise even in perfect foresight equilibrium.

3 Extensions

We now consider two extensions. First, the implications of ex ante heterogeneity, in terms of class, wealth or status. Second, the implications of our model for the recent controversy regarding the effect of Hepatitis B upon the sex ratio.

3.0.1 Ex ante heterogeneity

We now consider the implications of ex-ante heterogeneity of status in the population. Let us assume that there are two classes (or castes), H and L, with measures μ and 1 respectively. Assume 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 status i, where $i \in \{L, H\}$. Assume also that the preference parameters are identical across the two classes.[13]

Consider first the upper class. If a girl married to a high class person is preferable to a boy married to a low class person (i.e. if $u_B + \rho^L < u_G + \rho^H$), and if c is sufficiently small, the equilibrium sex ratio in the upper class, r_H^*, satisfies

$$u_B + r_H^* \rho^H + (1 - r_H^*)\rho^L - 2c = u_G + \rho^H. \tag{5}$$

The left hand side of the above expression shows the expected value of boy, less the expected cost of ensuring a girl; the right hand side shows the value of a girl. Clearly, $r_H^* < 1$ if $u_B - u_G > 2c$.

Now let us consider the lower class. A measure $\frac{1-r_H^*}{1+r_H^*}\mu$ of upper class boys are available, and if the sex ratio in the lower class is r_L, the measure of lower class girls is $\frac{r_L}{1+r_L}$. So each lower class girl has a probability $\frac{(1+r_L)(1-r_H^*)}{r_L(1+r_H^*)}\mu$ of marrying an upper class boy. This leaves a measure $\left[\frac{r_L}{1+r_L} - \frac{1-r_H^*}{1+r_H^*}\mu\right]$ of lower class girls who are matched with a measure $\frac{1}{1+r_L}$ of lower class boys. Consequently, if the ratio of the former to the latter is less than one, some lower class boys are left unmatched, while girls will be left unmatched if the ratio is greater than one. The payoff to lower class boys is therefore given by

$$U^L(r_L, r_H^*) = u_B + \min\left\{r_L - \frac{(1+r_L)(1-r_H^*)}{1+r_H^*}\mu, 1\right\}\rho^L. \tag{6}$$

The payoff to lower class girls is given by

$$\begin{aligned} V^L(r_L, r_H^*) &= u_G + \frac{(1+r_L)(1-r_H^*)}{r_L(1+r_H^*)}\mu\rho^H \\ &\quad + \min\left\{\frac{1+r_H^*}{(1+r_H^*)\,r_L - (1+r_L)\,(1-r_H^*)\,\mu}, 1\right\}\rho^L. \end{aligned} \tag{7}$$

The equilibrium sex ratio in the lower class, r_L^*, is determined as follows. If $\left|U^L(1, r_H^*) - V^L(1, r_H^*)\right| <$

[13] 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.

$2c$, then $r_L^* = 1$. Otherwise, r_L^* is such that $\left|U^L(1, r_H^*) - V^L(1, r_H^*)\right| = 2c$. The following observations are immediate from this analysis. $r_L^* > r_H^*$, that is the sex ratio is more favorable to girls among the lower class than among the upper class. This arises since the imbalance in the sex ratio amongst the upper 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_L, the probability that a lower class boy gets a partner increases with r_H^*). Indeed, it is possible that the sex ratio among the lower class is biased towards boys, if the measure of the upper class is sufficiently large. This is probably empirically less likely, but the absence of any bias against girls in outcomes is possible for a large range of parameters, even though lower class preferences are as male biased as upper class ones.

The results here are relevant for empirical work, suggesting that one should observe more male biased sex ratios in the upper class as compared to the lower class. 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.

From a welfare point of view, note that parental sex selection reduces ex ante expected utility in the upper class, under similar assumptions as in our simple model (i.e. if $u_G - u_B + 2c + 2(\rho^H - \rho^L) > 0$). More interesting is the effect on the lower class, since selection in the upper class raises the payoffs to girls, while lowering the payoff to boys. A benchmark case is when $r_L^* = 1$, so that there is no selection in the lower class. Now if $\rho^H < 2\rho^L$, 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. So sex selection reduces welfare also in the lower class. Suppose now that $r_L^* < 1$. 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 class, on the assumption that parameter values are such that there is no selection for girls in this class.[14]

These findings in this section are related to the famous Trivers-Willard (1971) hypothesis of evolutionary biology. This applies to animals where mating is non-monogamous, where high quality males are able to mate many times, while low quality males fail to mate. This implies that healthier mothers, who can expect higher quality offspring, have an incentive to produce boys. On the other hand, less healthy mothers have an incentive to produce girls. Note that the mechanism here is quite different, and arises from the imbalance in the sex ratio, since mating is assumed to be monogamous. It is also related to Edlund (1999), who

[14] 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 class.

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. [15] We are also able to analyze the welfare implications of selection, and unbalanced sex ratios in this context.

3.1 Hepatitis B and the sex ratio

A recent paper by Oster (2005) argues that male biased sex ratios may be partially explained by hepatitis B, since infection by the virus makes mothers more likely to bear boys. Her estimates indicate that hepatitis B is responsible for about 20% of the excess of boys in China, but only about 5% in the case of India. However, these estimates assume that there is no behavioral response by parents to the incidence of the virus (as Oster acknowledges). We now consider how implications of biased sex ratios, arising from hepatitis B infection, upon the equilibrium behavior of the sex ratio. Let us suppose that uninfected mothers have a probability p^u of having a boy, while infected mothers have a probability $p^h > p^u$. We may think that $p^u = 0.5$, although this is not necessary for what follows. Let λ be the fraction of infected mothers.

Consider first a society where there is no significant gender bias so that there are no sex selective abortions. That is, let us assume that $u_B \simeq u_G$, with c being large relative to $|u_B - u_G|$, so that a parent is content to accept a child irrespective of gender. Let us also assume that the incidence of hepatitis B infection, λ, is small. In this case, there is no behavioral response to the rate of hepatitis B infection (λ), and the observed proportion of boys in the population depends linearly on λ:

$$p(\lambda) = p^u + \lambda(p^h - p^u). \tag{8}$$

Thus an increase in the incidence of hepatitis B raises the proportion of boys at rate $p^h - p^u$. The sex ratio, $r(\lambda) = (1 - p(\lambda))/p(\lambda)$.

[15] We conjecture that our results would also hold when agents are strictly ordered ex ante in terms of expected quality, provided that there was an element of ex post heterogeneity which could produce different rankings with some probability.

Now let us consider a society where there is gender bias that is large enough to induce sex selective abortions. In this case, the behavioral response offsets any change in hepatitis B infection. Our analysis depends on whether mothers know about the link between hepatitis B and the sex ratio at birth or not. Since the hypothesized link between hepatitis B and the sex ratio is relatively new, and unknown even to most medical professionals in these countries, the most plausible assumption is that mothers assume that the probability of having a boy is 0.5, regardless of hepatitis B status. This implies that the equilibrium condition, for a mother to be indifferent between having a girl and trying again is as before, i.e. $U(r^*) - V(r^*) = 2c$. Thus the equilibrium sex ratio is invariant with respect to λ, and the behavioral response *completely offsets* the direct effect of hepatitis B on the sex ratio.

This conclusion must be modified, but only somewhat if mothers are aware of the link between hepatitis B and the sex ratio. The analysis here depends upon whether an individual mother observes her hepatitis B status or not. Let us assume the former. At any sex ratio r, the expected payoff from trying again is greater for an infected mother than for an uninfected mother, since the infected mother has a higher probability of having a boy. This implies that if an infected mother is indifferent from having a girl and aborting the foetus and trying again, the uninfected mother strictly prefers to accept the girl. Conversely, if the uninfected mother is indifferent, the infected mother strictly prefers to continue trying till she has a boy. This has the straightforward implication that the *observed* difference in frequencies of boys between infected and uninfected mothers is greater than the difference $p^h - p^u$.[16] This result is robust, in the sense that it applies as long as infected mothers have some inkling of their infection (i.e. they assign higher probability to being infected than uninfected mothers).

Turning to equilibrium, the indifference condition depends upon which type is marginal, i.e. which type has some mothers trying again while others accept a girl. This in turn depends upon how large λ, the fraction of infected mothers, relative to the equilibrium proportion of boys. The indifference condition characterizing equilibrium may be written as

$$p^j U(r^*) + (1 - p^j) V(r^*) - 2c = V(r^*), \tag{9}$$

where

$$p^j = \begin{cases} p^h \text{ if } \lambda + (1-\lambda)p^u \geq 1/(1+r^*) \\ p^u \text{ if } \lambda + (1-\lambda)p^u < 1/(1+r^*). \end{cases} \tag{10}$$

Note that the indifference condition (9) is constant in λ except at the point where $\lambda + (1-\lambda)p^u - 1/(1+r^*)$ changes sign. This implies that changes in λ will have no effect on the

[16] This applies as long as one has an interior equilibrium where some mothers accept girls and others try again.

equilibrium sex ratio r^* unless these changes induce a "regime-change", where the indifferent mother switches type. That is, even if hepatitis B affects the proportion of boys directly, the behavioral response may well completely offset this effect.

The basic point here is that if the sex ratio imbalance reflects parental preferences, then exogenous changes in the sex ratio, due to factors such as hepatitis B, will be offset, at least in part, by the behavioral response of parents.

4 Parental Investment

We now consider the implications of parents investing in their children in order to improve their match quality. Peters and Siow (2002) set out a model of pre-marital investments in a frictionless economy.[17] There is fixed measure of boys, with an associated exogenous distribution of parental wealth. Similarly, there is a fixed measure of girls, with a possibly different parental wealth distribution. 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.

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 sharp discontinuity in payoffs when the sex ratio changes from $r = 1$ to r strictly less than but close to one. Assume that the parent derives a direct benefit $b(x)$ from an investment of x in a child, and incurs a cost $\tilde{c}(x)$. Define the net cost of investment in a child, $c(x) = \tilde{c}(x) - b(x)$, and assume that this is 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^{**}, at a cost $c(x^{**})$, where $c'(x^{**}) = 1$, since efficiency requires that the marginal cost equals the marginal benefit to the other partner, one. 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

[17] See also Burdett and Coles (200?), who analyse pre-marital investments in a frictional search model.

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 $u_G + \rho + x_B^{**}(r) - c(x_B^{**}(r)) > u_B$, 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. In other words, if preferences are gender biased so that boys are strictly preferred to girls when both will married for sure, but a married girl is preferred to a single boy, then an equilibrium will fail to exist when we allow for parental investments and sex selection.

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 $x + \rho_G + \varepsilon$, where ε is distributed on $[0, \bar{\varepsilon}]$ according to a continuous strictly increasing cumulative distribution function $F(.)$. Similarly, if the investment in girl is x, then realized quality is given by $x + \rho_B + \eta$, where η has a continuous strictly increasing cumulative distribution function $G(.)$ with support $[0, \bar{\eta}]$. As before, we assume that the parent derives a direct benefit $b(x)$ from an investment of x in a child of sex i, and incurs a cost $\tilde{c}(x)$. The net cost of investment, $c(x) = \tilde{c}(x) - b(x)$, is assumed to be strictly convex and eventually increasing.

We proceed by first considering investment decisions conditional on a given sex ratio r. Let us first consider efficiency in investments, conditional on a given sex ratio 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 $c'(x_G^{**}) = 1$. 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 $c'(.) = 1$. 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, and thus the first best efficient level of investment in a boy, x_B^{**}, must satisfy $c'(x_B^{**}) = r$, i.e. the marginal cost must equal the expected marginal benefit.

We now turn to equilibrium. For any profile of investments, a stable matching will be assortative, so that the best quality boys will be matched with the best quality girls, and so on. Suppose that all boys invest the same amount x_B and all girls invest the same amount x_G. Since the top r fraction of boys will only be matched, this corresponds to those having a realization of $\varepsilon \geq \underline{\varepsilon}$ where $F(\underline{\varepsilon}) = 1 - r$. In this case, a boy of type $\varepsilon \geq \underline{\varepsilon}$ will be matched with a girl of type $\phi(\varepsilon)$, where

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

More generally, if all boys invest x_B and a parent invests $x_B + \Delta$ in his son, the realized match of his son, as a function of his realized quality ε will be that corresponding to $\varepsilon + \Delta$,as long as $\varepsilon + \Delta \geq \underline{\varepsilon}$:

$$\phi(\varepsilon + \Delta, r) = G^{-1}\left[\frac{1}{r}F(\varepsilon + \Delta) - \frac{(1-r)}{r}\right] . \tag{11}$$

Thus the matching process defines the benefits from additional investment – by investing more, a the parent of a boy improves his match quality for any realization of ε, and also increases the probability that he is matched at all. Similarly, one can write down a similar equation for investment in a girl, showing how realized match quality improves with additional investment. The difference is that additional investment does not increase the probability of being matched for a girl, since there are at least as many boys as girls.

We now consider equilibrium investments, solving for an equilibrium where investment is the same on each side of the market. Suppose that all boys invest x_B and a parent invests $x_B + \Delta$ in his son. The expected payoff in the marriage market, as a function of Δ, is given by

$$\int_{\underline{\varepsilon}-\Delta}^{\bar{\varepsilon}} (\phi(\varepsilon + \Delta, r) + \rho_B + x_G) f(\varepsilon) d\varepsilon = \int_{\underline{\varepsilon}-\Delta}^{\bar{\varepsilon}} G^{-1}\left[\frac{1}{r}F(\varepsilon + \Delta) - \frac{(1-r)}{r}\right] f(\varepsilon) d\varepsilon.$$

To solve for an equilibrium where all boys invest the same amount x_B^*, while all girls invest the same amount x_G^*, we differentiate the expected payoff (match value minus cost) with respect to Δ and set it equal to zero at $\Delta = 0$, giving us the first order condition

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

where ϕ' is the derivative of ϕ with respect to x (or ε).This equation has a natural interpretation. By investing a little more in my son, I improve his match quality by $\phi'(\varepsilon, r)$ for every realization of ε where he does get matched. Additionally, I also increase his probability of getting matched, at a rate $f(\underline{\varepsilon})$, and in this event, my payoff equals the absolute payoff of the worst quality girl, $\rho_B + x_G^*$. This benefit must equal the marginal cost of investment.

In order to shed further light on this first order condition, we differentiate equation (11), to obtain

$$\phi'(\varepsilon, r) = \frac{f(\varepsilon)}{rg(\phi(\varepsilon))}.$$

Thus the first order condition for investment in boys can be re-written as

$$\frac{1}{r}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} \frac{f(\varepsilon)}{g(\phi(\varepsilon))} f(\varepsilon)d\varepsilon + f(\underline{\varepsilon})(\rho_B + x_G^*) = c'(x_B^*). \tag{12}$$

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

$$\int_0^{\bar{\eta}} \left(\phi^{-1}\right)'(\eta)g(\eta)d\eta = r\int_0^{\bar{\eta}} \frac{g(\eta)}{f(\phi^{-1}(\eta))} g(\eta)d\eta = c'(x_G^*). \tag{13}$$

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 12 equals one, and the second term is absent, so that $c'(x_B^*) = 1$, and similarly $c'(x_G^*) = 1$. 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.

Since the integrals in 12 and 13 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

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

$$c'(x_G^*) = r.$$

Thus we see that there are excessive investment in boys – the marginal cost of investment exceeds one, while efficiency at the investment stage requires $c'(x_B^*) = r < 1$. There are insufficient investments in girls, since $c'(x_G^*) = r$ rather than the efficient level, one.

Our results are relevant in the context of recent empirical work by Wei and Zhang (2009), arguing that the high savings rate in China is attributable to the sex ratio imbalance. They argue that parents of boys feel compelled to invest more, thus raising the overall savings rate. Our analysis shows that while this is indeed the case, this is counterbalanced by the reduced investment incentive for parents of girls. If we assume that the costs of investment are quadratic (so that marginal costs are linear), 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, on the right hand side, $\frac{1+r^2}{1+r}$, is increasing in r, while the derivative of sign of the second term is ambiguous, since both the numerator and denominator are increasing in r. Thus it theoretical ambiguous whether a sex ratio imbalance gives rise to an overall increase in parental investment and savings rates.

We now turn to determination of the equilibrium sex ratio. For $r \leq 1$, we define the overall payoffs to boys and girls, given the equilibrium investments as

$$\tilde{U}(r) = u_B + r[\rho_B + \mathbf{E}(\eta) + x_G^*] - c(x_B^*),$$

$$\tilde{V}(r) = u_G + \rho_G + \mathbf{E}(\varepsilon | \varepsilon \geq \underline{\varepsilon})] + x_B^* - c(x_G^*).$$

We see therefore that the payoff difference between boys and girls is an increases faster with r, since equilibrium investments in boys are decreasing in r and while those in girls are increasing in r. Thus, if an equilibrium exists, it will be unique. The proposition below shows that an equilibrium will exist in the uniform case provided that the dispersion in idiosyncratic values is sufficiently large, i.e. $\bar{\varepsilon}$ is large enough.

Proposition 2 *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. An equilibrium exists in the game where parents choose the gender of their child and how much to invest.*

Proof. Equation (13) shows that x_G^* is a continuous function of r for all $r \in [0,1]$. Equation (12) shows that x_B^* is a continuous function of r for all $r \in [0,1]$ as long as $f(.)$ is continuous – in particular, as long as $f(\varepsilon) \to 0$ as $\varepsilon \downarrow 0$. 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 $\tilde{h}(0) = u_B - u_G - \rho_G - \bar{\varepsilon} - 2c < 0$,[18] 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 (12) 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 assumed to be 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. ■

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. Nevertheless, in equilibrium there must unbalanced sex ratios in the marriage market, and this is welfare reducing. Furthermore, the investment decisions themselves are distorted relative to what the social planner would want. As we have seen, if the social planner could enforce a balanced sex ratio, then investment decisions would also be efficient, so that overall efficiency is ensured.

5 Bride Prices

We have assumed that there are no transfers possible in the marriage market. Suppose that the more abundant sex (boys) compete for the scarcer sex by making transfers, say a bride price. We analyze a bride price system under two possible situations. We first consider a frictionless market, and then go on to consider market frictions. Before proceeding to the analysis, it is worth relating our analysis to current institutional arrangements. Following Becker (1981), an imbalance in the marriage market implies that the scarcer sex – females in this case – will be able to command a bride price. However, it is dowries (we use the term to denote groom-prices) that are the norm in most parts of India. Indeed, there is some evidence that dowries have increased over the twentieth century, and have also been established in areas where they were not previously customary – see, for example, Rao (1993).[19] This appears to be the case for two reasons. First, dowries may partially be a pre-mortem bequest to girls (Botticini and Siow, 2003; Zhang and Chan, 1999) and this

[18] If there is a positive measure of boys and measure zero of girls, then neither side has any incentive to invest.

[19] Apart from the data from six villages used used by Rao, there is little systematic quantitative evidence on dowry payments in India. However, informal evidence suggests that dowry payments have increased in the long term.

component would tend to rise with incomes and wealth. Second, rapid population growth in the twentieth century, in conjunction with the age-difference in marriage has given rise to the "marriage squeeze" – see e.g. Bhatt and Halli (1999). [20] The magnitude of excess supply of women implied has been quite large – to illustrate, if cohort size grows at 2% per annum, and the age-difference in marriage is five years, then a balanced sex ratio implies over 10% excess supply of women. In other words, it appears that increase in dowries over the twentieth century in India reflects supply-demand factors; in consequence, one should expect that recent and ongoing changes in the sex ratio will also be reflected in prices. We should note that in recent years, population growth in India has declined, so that the marriage squeeze is less important. This makes the imbalance in the sex ratio even more worrying.

5.1 Walrasian Markets

Assume that the ex-post marriage market is Walrasian. Our focus is on a rational expectations equilibrium, where parents make their initial choices (regarding gender) anticipating a bride price, that in turn equals the realized bride price. Let t denote the transfer from boys to girls, i.e. the bride price. In a Walrasian market, an agent on the long side must be indifferent between marrying at the market price and staying single. So $t = \rho_B$ if $r < 1$ and $t = -\rho_G$ if $r > 1$.If $r = 1$, then any $t \in [-\rho_G, \rho_B]$ is a market clearing price. Let us now consider a rational expectations equilibrium, where parents at date 1 (the time the child is born) correctly forecast a t^*, and where the choices they exercise results in a sex ratio r^* such that t^* is a Walrasian price given r^*. We show first that the sex ratio cannot be unbalanced in a rational expectations equilibrium. Suppose that $r^* < 1$, so that $t^* = \rho_B$. In this case, any parent who has a girl strictly prefers not to exercise choice, since we have assumed that $u_B - u_G < \rho_B$. So r^* cannot be less than one. Similarly, one cannot have $r^* > 1$.

We now show that there is a continuum of rational expectations prices that support a single allocation, the efficient one with a balanced sex ratio, where the equilibrium transfer t^* satisfies

$$\frac{(u_B - u_G) - 2c}{2} \leq t^* \leq \frac{(u_B - u_G) + 2c}{2}. \tag{14}$$

To verify that this is indeed an equilibrium, note that the bounds lie within the interval $[-\rho_G, \rho_B]$, so that the equilibrium price is Walrasian. Furthermore, if the inequality is satisfied, a parent who has a girl will not find it optimal to exercise choice, and the same is true for a parent who has a boy. Notice that a Walrasian equilibrium permits gender bias –

[20] See Anderson (2003) for an alternative explanation for the persistence and spread of dowries with modernization.

t^* may be such that parents are better off with a boy or for that matter, a girl, since $c > 0$.

Our model so far is static, and assumes that the payoff from marriage (ρ_G or ρ_B as the case may be) accrues immediately as soon as the marriage is contracted. However, it is more plausible to think of the payoff from marriage as a flow payoff, in which case ρ_G or ρ_B represent the discounted present value of flow payoffs. Now suppose that agents are credit constrained, so that there exists an upper bound $\bar{t}$ such that $|t| \leq \bar{t}$. That is, the bride price (or dowry) that can be paid at the time of marriage cannot exceed $\bar{t}$. Furthermore, let us suppose that $\bar{t} < \frac{(u_B - u_G) - 2c}{2}$, the minimum bride price that is required to support the efficient allocation. This in itself does not create any complications, if no element of irreversibility in marriage – if marriage is completely flexible, and men are in excess supply, then the continuation of marriage can be made contingent upon the payment of a "flow" bride price. However, marriage has strong elements of irreversibility, particularly so in countries such as India or China, where divorce is relatively rare. This means that agents on the long side of the market, say men, will not be able to commit to the flow payments, since they have the incentive to renege once married. [21] The equilibrium sex ratio will therefore be given by

$$1 - r^*(\bar{t}) = \frac{(u_B - u_G) + (\rho_B - \rho_G) - 2\bar{t} - 2c}{\rho_B - \bar{t}}. \tag{15}$$

Thus credit constraints provide one explanation for why the equilibrium sex ratio might be unbalanced, even if there are prices in the marriage market.

5.2 Frictional Matching

The Walrasian model has an unattractive property that the equilibrium price moves discontinuously with the sex ratio. Marriage markets are hardly centrally organized, and idiosyncratic factors play an important role in partner choice. We therefore consider decentralized matching, with the bride-price being the outcome of bargaining. Let us now consider a frictional matching model, as in Rubinstein and Wolinsky (1985) or Mortensen and Pissarides (1994). Time is continuous, the time horizon is infinite, and agents discount the future at a common interest rate i. At any instant, there is a stock of unmarried boys, of measure μ, and a stock of unmarried girls of measure $x\mu$, so that x denotes the sex ratio in the stocks. Matches arrive according to a Poisson process, with arrival rate $m(x\mu, \mu)$. The matching function $m(.)$ is increasing in both arguments, differentiable, symmetric (i.e. $m(y, z) = m(z, y)$) and satisfies constant returns to scale. This last assumption implies that the analysis maybe conducted in terms of x, the sex ratio, without reference to absolute

[21] As Becker (1981) suggests, dowries are one off payments which necessary due to the limited transferability of utility within marriage.

market size μ. Accordingly, let $\alpha(x) = m(x, 1)$ denote the arrival rate of matches for a girl, so that the arrival rate of matches for a boy is $x\alpha$. It follows that $\alpha(x)$ is increasing in x, while $x\alpha(x)$ is decreasing in x, i.e. the arrival rate for either sex rises if the share of the opposite sex is larger in the population. Finally, we shall assume that matching becomes more efficient if the market is more balanced. More precisely, we assume that the sum of arrival rates, $s(x) = \alpha(x) + x\alpha(x)$, increases as the market becomes more balanced, i.e. $s(x)$ is strictly increasing (resp. decreasing) in x if $x < 1$ (resp. $x > 1$).

Suppose that a boy and a girl are matched and negotiate a marriage. We assume that there are no credit constraints, so that the bride-price $\frac{t}{i}$ that is paid from the boy to a girl is freely negotiated. Given this bride price, the value of a married boy may be written as

$$U^m = \frac{u_B + \rho - t}{i}, \tag{16}$$

where u_B and ρ represent flow utilities. We have assumed that $\rho_G = \rho_B = \rho$ – this is without loss of generality given unrestricted transferability of utility.[22] Similarly, the value of a married girl can be written as

$$V^m = \frac{u_G + \rho + t}{i}. \tag{17}$$

The value of a single boy, as a function of x and the "market" bride price t that he anticipates paying satisfies the asset pricing equation

$$iU(x, t) = u_B + x\alpha(x)(U^m - U). \tag{18}$$

This may be written as

$$U(x, t) = \frac{u_B}{i} + \frac{x\alpha}{i(x\alpha + i)}(\rho - t). \tag{19}$$

Similarly, the value of a single girl is given by

$$V(x, t) = \frac{u_G}{i} + \frac{\alpha}{i(\alpha + i)}(\rho + t). \tag{20}$$

We assume that the bride price is determined by Nash bargaining between the two parties. That is the equilibrium bride price t^* is given by the Nash bargaining solution where the

[22] If ρ_B differs from ρ_G, let $\rho = (\rho_B + \rho_G)/2$, and let the actual bride price $\hat{t} = t + \rho - \rho_G$. The analysis that follows applies with this translation.

outside options are given by $U(x,t)$ and $U(x,t)$.[23] Now, in a steady state equilibrium, the negotiated bride price between the matched pair, t^*, must itself be equal to the anticipated market price t. Thus we obtain the condition:

$$U^m(t^*) - U(x,t^*) = V^m(t^*) - V(x,t^*). \tag{21}$$

This allows us to solve for the market bride price as a function of x :

$$t^*(x) = \frac{\rho(1-x)\alpha(x)}{\alpha(x)(1+x)+2i}. \tag{22}$$

We may now use the equilibrium bride price to compute the equilibrium value as a function of x alone. That is $\tilde{U}(x) = U(x, t^*(x))$ is given by

$$\tilde{U}(x) = \frac{u_B}{i} + \frac{2\rho x\alpha(x)}{[\alpha(x)(1+x)+2i]i}. \tag{23}$$

$$\tilde{V}(x) = \frac{u_G}{i} + \frac{2\rho\alpha(x)}{[\alpha(x)(1+x)+2i]i}. \tag{24}$$

With parental choice, the equilibrium sex ratio (in stocks) x^* must be so that the difference in values equals twice the one time cost of trying again, c:

$$\tilde{U}(x^*) - \tilde{V}(x^*) = 2c. \tag{25}$$

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, $\alpha(x) = x\alpha(x)$ when $x = 1$) and thus it is optimal to try again on having a girl.

We now turn to the implications for the flow of births. Let us assume that the flow of new births is exogenously given at g,[24] and let θ be the fraction of births that are girls. Let μ be the measure of the stock of boys, and assume that the instantaneous death rate is δ. Thus the steady state flows must satisfy

$$\alpha x\mu + \delta\mu = (1-\theta)g. \tag{26}$$

$$\alpha x\mu + \delta x\mu = \theta g. \tag{27}$$

[23] 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.

[24] This is a simplification, since the flow of births depends on desired family size and upon the matching rate, both of which depend upon the sex ratio.

Solving these equations, we get θ as

$$\theta = \psi(x) = \frac{g + \delta\alpha(x-1)}{2g}. \tag{28}$$

That is, if x^* is the required sex ratio in the stock of the unmatched, the proportion of girls in the flow of births is given by $\theta(x^*)$.

Consider now the implications of population growth and the age gap at marriage when intrinsic son preference is absent (the same argument applies when son preference is weak relative to c). We may model this by assuming that the proportion of the flow of girls, in the absence of selection, $\hat{\theta}$, being greater than one-half. In the absence of selection, the sex ratio in the stock will be $\hat{x} = \psi^{-1}(\hat{\theta}) > 1$. Thus $\tilde{V}(\hat{x}) < \tilde{U}(\hat{x})$, and if c is sufficiently small, it is optimal to select for boys. Thus the equilibrium sex ratio x^* must satisfy the indifference condition (25), and the payoff of boys must exceed the payoff of girls. This implies that $x^* > 1$, and therefore the sex ratio in the marriage market is biased against girls.

Turning to welfare, let us consider the expected welfare of the parent as a function of $x, W(x)$. This is given by

$$W(x) = (1-\theta(x))\tilde{U}(x) + \theta(x)\tilde{V}(x) - (1-2\theta)c. \tag{29}$$

$$W'(x) = \left\{(1-\theta)\tilde{U}'(x) + \theta\tilde{V}'(x)\right\} + \left\{\theta'(x)[\widetilde{V(x)} + 2c - \tilde{U}(x)]\right\}. \tag{30}$$

Let us call the first term in curly brackets the "match efficiency effect" – this is the derivative of the (weighted) sum of the utilities of the two sexes with respect to x. This is proportional to

$$\theta(x)\alpha'(x) + (1-\theta(x))\{x\alpha'(x) + \alpha(x)\}. \tag{31}$$

Now since $s'(x) = \alpha'(x) + \{x\alpha'(x) + \alpha(x)\} \gtreqless 0$ as $x \lesseqgtr 1$, and since $\theta(x)$ is an increasing function of x that equals one-half at $x = 1$, the expression in (31) has the same properties, i.e. it is zero at $x = 1$, and strictly positive when $x < 1$, and strictly negative when $x > 1$. In other word, since the efficiency of matching is maximized when the market is balanced, the match efficiency effect contribution to welfare increases as the market becomes more balanced.

Turning to the second term in curly brackets, this is simply 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 (30) 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.

Consider next the case where there is little or no gender bias, and population growth so that $x^* > 1$. Here, the social optimum x^{**} will be smaller than x^*, so that there is too little selection in equilibrium. Thus the main finding of our simple model without prices appears to be robust.

With frictional matching it is not the case that $x = 1$ is socially optimal. From equation (30), at $x = 1$ the match efficiency term is zero but the private benefit term is negative so that welfare is decreasing in x at $x = 1$. Thus the welfare optimal level of x lies between x^* and 1. The one finding of the simple model (in section 2) that appears not to be robust is the result that the optimal sex ratio is one. With frictionless matching, match efficiency is a non-differentiable function of the sex ratio, r, since the number of matches per unit measure of population is $\frac{r}{1+r}$ as long as $r < 1$ and $\frac{1}{1+r}$ if $r > 1$. 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.

Our results in this section are related to those obtained in the literature on the efficiency of job creation in search models of unemployment pioneered by 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, that the equilibrium has too many boys relative to the welfare optimum. In this context, the search literature has also noted that an appropriate assignment of bargaining power between the two sides can ensure an efficient allocation (Hosios, 1990). In the present context, efficiency requires that women have greater bargaining power than men. This seems somewhat unlikely – indeed, the inferior status of women in traditional societies would reduce their bargaining power relative to men. 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. From the basic indifference condition (25), the effect of a change in c upon the equilibrium sex ratio is given by

$$\frac{dx^*}{dc} = \frac{2}{\tilde{U}'(x)\mid_{x=x^*} - \tilde{V}'(x)\mid_{x=x^*}}, \tag{32}$$

which is positive if $x^* < 1$ since the match efficiency effect implies that $U'(.) > V'(.)$. Thus, technological progress in sex selection has the effect of reducing sex ratio, as intuition suggests. To examine the effect on equilibrium welfare, define $W^*(c) = W\left(x^*(c)\right)$. In equilibrium, it is optimal for a parent to accept the lottery that nature deals in terms of the sex of child. Using this, and the fact that the difference in values between a boy and a girl equals $2c$, we may rewrite equilibrium welfare as

$$W^*(c) = \tilde{V}(x^*(c)) + c. \tag{33}$$

$$\frac{dW^*}{dc} = \left.\frac{\partial \tilde{V}}{\partial x}\right|_{x=x^*} \frac{dx^*}{dc} + 1. \tag{34}$$

$$= \frac{2\tilde{V}'(x)_{|x=x^*}}{\tilde{U}'(x)\mid_{x=x^*} - \tilde{V}'(x)\mid_{x=x^*}} + 1. \tag{35}$$

Now $\tilde{V}'(x)\mid_{x=x^*} < 0$ but 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. Thus we conclude that welfare is an increasing function of c. Thus technological progress reduces welfare. Notice that welfare optimal level of x is also an increasing function of c: from equation (30), an increase in c increases the second (private benefit) term, thereby increasing x^{**}.

We summarize our results as follows:

Proposition 3 *Let $u_B - u_G > ci$, and let there be prices in a marriage market with frictional matching, where the match efficiency is maximized when the sex ratio is balanced. Both the equilibrium sex ratio and the welfare optimal sex ratio are biased towards boys, with the equilibrium having excessive boys compared to the welfare optimum. Technological progress that reduces c reduces welfare.*

Our analysis in this section has explored the role of marriage market prices in the context of parental choice. The essential insights of our simple model in section 2, without any prices, appear to be robust to allowing for bride prices, provided that this market is subject to frictions. Specifically, we find that the equilibrium sex ratio tends to be inefficiently low, so that there are two many boys relative to girls. We also find that technological progress aggravates the problem and reduces welfare.

In this context, we may return to the arguments of Kumar (1983), who suggested that the scarcity of women could play a positive role, by increasing their value. While this is true, it is also the case that markets require appropriate prices in order to work. Specifically, prices must be Walrasian in order to ensure efficiency. Markets without prices – as in the simple marriage market model of section 2 – or those where pricing is not Walrasian, do not necessarily ensure efficient allocations.

6 Fertility, selection and the sex ratio

Our analysis in this section has two purposes. First, we shall explore the nature of selection decisions in societies with pronounced gender bias (such as those in South or East Asia). This will allow us to interpret the micro empirical evidence on sex ratios and selection decisions at family level. It will also shed light on the role of China's one-child policy upon gender imbalance. Second, we shall investigate the implications for policy societies without pronounced gender bias, such as the UK or the US, where the desire for selection is driven by family balancing considerations. Our analysis will be conducted assuming that there are no prices in the marriage market.

6.1 Gender biased societies

Parents normally have more than one child. Our simple model of section 2 continues to apply in this case, as long as gender preferences are independent of family composition, and as long as marginal reproductive value is constant. However, it is plausible that parents' relative preferences between a boy and girl will, in general, depend upon the gender of the child that they already have. It is also likely that reproductive value displays an element of diminishing returns, at least in the context of current parental preferences.

Suppose that a family has m boys and f girls, and suppose that ℓ of these children are matched in the marriage market. The utility to the parents is given by $U(m, f) + \rho(\ell)$. We assume that both $U(.)$ and $\rho(.)$ are strictly concave functions. In particular, we assume that for any given family size n, $U(m + 1, n - m - 1) - U(m, n - m)$ is strictlyl decreasing in m. Under this assumption imply that incentives 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 the survey of ever-married women carried out in India in 1998, and analyzed by Jha et al. (2006). The survey of 1.1 million households found that the sex ratio is more biased against girls if the first or first two children are girls, than if the first or the first two children are boys.

Assume for simplicity that family size is exogenously given at $n \geq 1$.It is often argued by demographers that parents have a strong preference for at least one boy, and that this preference underlies gender based stopping rules, such as having children until the first boy. To model this, let us assume that

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

so that the marginal utility of having a boy as compared to a girl when you already have $n-1$ girls is larger than the cost of selection, 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.

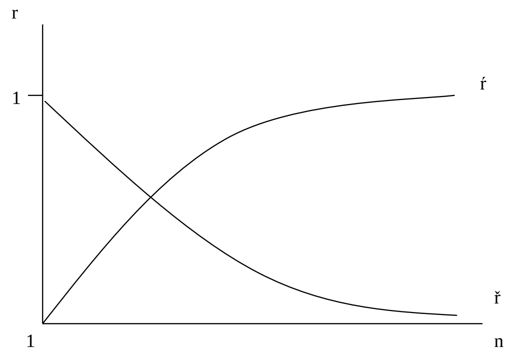
Suppose that the sex ratio is sufficiently close to 1 so that the reproductive value of a family of any composition is approximately equal to $\rho(n)$, independent of family gender composition. Under these assumptions, it follows that the optimal strategy is to not select, only at the last birth, and if all $n-1$ previous births have been girls. The sex ratio corresponding to families following this strategy is given by $\hat{r}(n)$:

$$\hat{r}(n) = \frac{(0.5)^{n-1}\left\{\frac{n-1}{2n}\right\} + \left[1-(0.5)^{n-1}\right]}{(0.5)^{n-1}\left\{\frac{n+1}{2n}\right\} + \left[1-(0.5)^{n-1}\right]}. \tag{36}$$

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

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

The table shows that $\hat{r}$ 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. However, at low values of n such as $n = 2$, 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, since clearly, as n declines, the sex ratio declines as well, so that reproductive value diverges considerably from $\rho(n)$, depending on family composition. We now take this 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

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

Since the payoff from keeping a girl is given by $U(0, n) + \rho(n)$, the payoff gain from selection is given by

$$[U(1, n-1) - U(0, n)] - (1-r)(\rho(n) - \rho(n-1) - 2c. \quad (37)$$

Let $\tilde{r}(n)$ be the value of r such that (37) equals zero. Since the expression in (37) is increasing in r, selection is optimal at the last birth for $r \geq \tilde{r}(n)$ and non-selection is optimal if this inequality is reversed. Thus the equilibrium sex ratio for any value of $n, r^*(n)$ is given by

$$r^*(n) = \max\{\tilde{r}(n), \hat{r}(n)\}.$$

Fig. 1 graphs the functions $\hat{r}(n)$ and $\tilde{r}(n)$. $\hat{r}$ is an increasing function while $\tilde{r}$ is a decreasing function, it follows that there exists a critical value $\tilde{n}$ such that $r^* = \tilde{r}$ for $n \leq \tilde{n}$

and $r^* = \hat{r}$ 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 $\hat{r}$ is such that (37) is strictly positive, given that $\hat{r} > \tilde{r}$. 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 $\hat{r}$ is such that (37) is strictly negative, given that $\hat{r} < \tilde{r}$. Thus only some families select, while others do not, and the sex ratio $\tilde{r}$ 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 increases the sex ratio, but further declines will tend to reduce 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 $\lambda\hat{r}(n_1) + (1 - \lambda)\ \hat{r}(n_2)$ where λ is the population weight of families with size n_1, and will therefore lie in the open interval $(\hat{r}(n_1),\ \hat{r}(n_2))$.The sex ratio will be more biased towards boys in smaller families, since they are more likely to exercise selection.

Now consider the case where n_1 and n_2 are both to the left of $\tilde{n}$. The aggregate sex ratio must lie in the *closed interval* $[\hat{r}(n_2),\ \hat{r}(n_1)]$. From equation (37), we see that at aggregate sex ratio $\hat{r}(n_2)$ where larger family is indifferent between selecting and not selecting, the smaller family must strictly prefer not to select. Now if all families of size n_2 select, their sex ratio will be $\tilde{r}(n_2)$, and thus any sex ratio greater than $(1 - \lambda)\tilde{r}(n_2) + \lambda$ can be achieved by these families alone selecting.

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).[25] 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

[25] 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.'

to select may be greater in urban areas, as our discussion in section 3.0.1 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 two children, and the first is a girl, the incentive to select for a boy is stronger than when they can have only one child, due to diminishing "marginal utility" for girls, and since a grandchild is assured. Thus, it is far from clear that China's one-child policy has been responsible for the adverse movement in the sex ratio.

6.2 Societies without generalized gender bias

We now turn to the analysis in the case of 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). [26] The American Society of Reproductive Medicine has taken a more positive position : "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, this contrasts with considerable evidence that parents have concerns for gender balancing within the family. Angrist and Evans (1998) use US census data and find that parents with two children of the same gender are 6% more likely to have a third child than parents who have two children of the same gender. While this data suggests that gender balancing may be a primary concern, there is also evidence that the sexes are not treated completely symmetrically. The data reported by Angrist and Evans shows that the probability of a third child is slightly (1-2%) greater for parents with two girls than for parents with two boys. Dahl and Moretti (2007) also present suggestive evidence that parents in the US, especially men, prefer boys to girls. [27]

Table 1: Prob. of having 3rd child

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

[27] 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.

1st two children	1980	1990
GB	0.372	0.344
BB or GG	0.432	0.407
Difference	0.060	0.063
GG	0.441	0.412
BB	0.423	0.401
Difference	0.018	0.011

Source: US census, Angrist and Evans (1998).

We now examine equilibrium in such a society. Suppose that family size is fixed exogenously at two. To reflect preferences for gender balancing, we shall assume that $U(1,1) > U(2,0)$ and $U(1,1) > U(0,2)$. We shall also assume that $U(2,0) > U(0,2)$ to 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). Let us assume that $U(1,1) > U(0,2) > 2c$, so that the parents of one girl have an incentive to select – if this condition is not satisfied, it is clear that there must be no selection, either in equilibrium or at the social optimum. Note that 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.

The overall payoffs to families of different compositions are given by equations (**??**), (**??**) and (**??**) in section 6.1. Suppose that $U(1,1) - U(2,0) > 2c$. In this case, there is an equilibrium where every parent exercises choice after having the first child and has a child of the opposite gender. Thus every family is gender balanced, consisting of one boy and one girl, and the sex ratio is balanced. Indeed, this is the only equilibrium – $r < 1$ cannot be an equilibrium outcome, since a parent whose first child is a boy has a strict incentive to exercise choice.

Suppose now that $U(1,1) - U(2,0) < 2c$. In this case, one cannot have an equilibrium with a balanced sex ratio, where all parents select after the first child, irrespective of gender. Nor can there be a balanced equilibrium where no parent selects. So we consider the equations

$$U(1,1) - U(0,2) - (1-r)[\rho(2) - \rho(1)] = 2c. \tag{38}$$

$$U(1,1) - U(2,0) + r(1-r)[\rho(2) - \rho(1)] + (1-r)^2 \rho(1) = 2c. \tag{39}$$

Equation (38) is the indifference condition for a parent whose first child is a girl, i.e. the requirement that $V_{BG} - V_{GG} = 2c$; let r^*_G be the value of r that solves this equation. Equation (39) is the indifference condition for a parent whose first child is a boy, $V_{BG} - V_{BB} = 2c$; let r^*_B be the value of r that solves this equation. We shall assume that parameter values are such that $\max\{r^*_G, r^*_B\} \geq 3/5$ (3/5 is the minimal sex ratio that can be achieved by selection for the second child, conditional on the gender of the first).[28] This ensures that equilibrium sex ratio is given by $\max\{r^*_G, r^*_B\}$. That is, if $r^*_G > r^*_B$, the equilibrium sex ratio is r^*_G, where all parents whose first child is a boy strictly prefer not to exercise choice, while a fraction of those with girls exercise choice. On the other hand, if $r^*_G < r^*_B$, the equilibrium sex ratio is r^*_B. In this case, all parents whose first child is a girl strictly prefer to exercise choice, while a fraction of those with boys exercise choice.

Our welfare criterion is the ex ante expected utility of the representative parent. If the equilibrium sex ratio is r^*_G, then a parent who has a girl is indifferent between selecting for a boy and not doing so. By not selecting, such a parent improves the sex ratio, so that in the aggregate two individuals get partners, thereby raising social welfare. Similarly, if the sex ratio is r^*_B, a parent who has a boy is indifferent between selecting for a girl and not doing so. In this case, by selecting, she exercises a positive externality on society. Thus, in either case the equilibrium is inefficient and social welfare can be increased by moving towards a more balanced sex ratio.

We now turn to a characterization of the global social optimum. Let us assume that $[U(1,1) - U(0,2) - 2c] - 2[\rho(2) - \rho(1)] < 0$. This condition states that the net gain from selection for a parent whose first child is a girl is lower than the marriage market cost of leaving two boys unmatched, where these boys belong a family where one child finds a partner. It will be satisfied, for example, if the parent does not wish to select if he knows that the selected boy will not find a partner (but is weaker than this condition). In this case, the global optimum corresponds to the a balanced sex ratio. This could either be due to ensuring that all parents exercise choice, if $(U(2,0) - U(1,1) - 2c) + (U(0,2) - U(1,1) - 2c) > 0$ – this condition states that the sum of benefits of selection for a pair of parents, one of which has a girl and the other has a boy, is greater than the sum of costs. Alternatively, if this inequality is reversed, social optimality is attained with no selection. We summarize these results in the following proposition, which is proved in the appendix.

Proposition 4 *If $U(1,1) - U(2,0) < 2c < U(1,1) - U(0,2)$, the equilibrium sex ratio equals $\max\{r^*_G, r^*_B\} < 1$, where some but not all parents exercise choice after the first child. Such an*

[28] Since we are discussing societies without generalized gender bias, this is the plausible range of parameters — the equilibrium sex ratio is unlikely to be very distorted. For completeness, we note that if $\max\{r^*_G, r^*_B\} < 3/5$, then the equilibrium sex ratio will equal 3/5.

equilibrium is inefficient and efficiency is improved by making the sex ratio more balanced. The welfare optimal allocation has a balanced sex ratio if $[U(1,1) - U(0,2) - 2c] - 2[\rho(2) - \rho(1)] < 0$. *If* $(U(2,0) - U(1,1) - 2c) + (U(0,2) - U(1,1) - 2c) > 0$, *the optimal allocation has every family exercising choice and being gender balanced; otherwise, the optimal allocation has no family exercising choice.*

7 Conclusions

The main contribution of this paper is to set out a simple model of parental choice regarding the sex of their child. In gender biased societies, where boys may be valued more than girls, parental choice results in too many boys, and reduces welfare. Although bride prices can improve efficiency, they will not result in an efficient outcome since the marriage market is likely to be subject to frictions. We have extended the simple model in a number of directions. These include an analysis of class differences in sex selection and of the effects of exogenous changes in the sex ratio, e.g. due to hepatitis B. The model can also be used to analyze choice when family balancing considerations become important. This allows us to shed light on the effects of the one-child policy in China, and suggests that while the one-child may be illiberal, it is unlikely to have been responsible for the adverse movement in the sex ratio in China.

We have also used this model to examine the possible effects of parental sex selection in advanced economies, where widespread gender bias is absent. If preferences (or the technology of selection) are not completely symmetric between the sexes, our model suggests that there may be concern regarding the aggregate sex ratio consequences of individual choice. The exact nature of gender preferences in developed societies remains an open question.

Our model throws up more questions than we have tried to answer. One important omission is the effect of sex selection upon fertility decisions – we have assumed family size to be exogenous throughout the paper. This is important in developed societies, where the link between family gender composition and fertility is well established. It is no less important in the two most populous countries in the world, China and India, where sex selection will no doubt continue in the years to come.

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 sum of the following terms is positive. That is, the required condition is

$$\left(1 - r + \frac{r}{\gamma}\right)(\rho_B + \mathbf{E}(\eta) + \left(1 - \frac{1}{\gamma} - \frac{r}{\gamma^2}\right)(\mathbf{E}(\varepsilon|\varepsilon \geq \underline{\varepsilon}) - \underline{\varepsilon}) \geq 0.$$

Since $\mathbf{E}(\varepsilon|\varepsilon \geq \underline{\varepsilon})$ is bounded above by $\bar{\varepsilon}$, and $\underline{\varepsilon} \geq 0$, a sufficient condition for the above inequality 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. That is,

$$-\left(\frac{1}{\gamma} + \frac{r}{\gamma^2} - 1\right)(\rho_G + \mathbf{E}(\varepsilon)) + \left(1 - r + \frac{r}{\gamma}\right)\mathbf{E}(\eta|\eta \geq \underline{\eta}) \leq 0.$$

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

A1 states that $\gamma + 1 > \gamma^2$, so the denominator is positive. It is easy to verify that the derivative of the right hand side of the above 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.

Proof of Proposition 4: If $r_G^* > r_B^*$, then at r_G^* a parent whose first child is a girl is indifferent between selecting and not selecting, while a parent whose first child is a boy strictly prefers not to select, verifying that the associated behavior corresponds to an equilibrium. Similarly, if $r_G^* < r_B^*$, then at r_B^*, the associated behavior corresponds to an equilibrium.

Let us now turn to welfare, as a function of selection decisions. With probability one-half, the first child is a girl. Let λ_i denote the fraction of parents who exercise choice after having a having a first child of sex $i, , i \in \{G, B\}$. Let $\lambda = \lambda_G - \lambda_B$ be a measure of the imbalance in the sex ratio, where λ is related to r by the equation $r = \frac{4-\lambda}{4+\lambda}$. Welfare is given by

$$W(\lambda, \lambda_B) = \frac{1-\lambda-\lambda_B}{4} V_{GG} + \frac{1-\lambda_B}{4} V_{BB}(r(\lambda)) + \frac{2+\lambda+2\lambda(B)}{4} V_{BG}(r(\lambda)) - \frac{2\lambda(B)+\lambda}{2} c. \tag{40}$$

We first show that the equilibrium outcome is inefficient as long as λ differs from zero.

$$\frac{\partial W}{\partial \lambda} = \frac{1}{4}[V_{BG} - V_{GG} - 2c] + \frac{1-\lambda_B}{4} \frac{\partial V_{BB}}{\partial \lambda} + \frac{2+\lambda+2\lambda_B}{4} \frac{\partial V_{BG}}{\partial \lambda}. \tag{41}$$

Suppose the equilibrium sex ratio equals r_G^*. In this case, the term in square brackets equals zero, since the parents who first have a girl are indifferent between choosing a boy and accepting nature's lottery. Since V_{BB} and V_{BG} are both decreasing in λ when this is positive as long as $\rho(1) > 0$ and $\rho(2) - \rho(1) > 0$, the derivative of W with respect to λ is negative at this equilibrium.

To deal with the case where the equilibrium sex ratio equals r_B^*, we re-write welfare as a function of λ and $\lambda_G, \hat{W}(\lambda, \lambda_G)$. The derivative of welfare with respect to λ is now given by

$$\frac{\partial \hat{W}}{\partial \lambda} = \frac{1}{4}[V_{BG} - V_{GG} - 2c] + \frac{1-\lambda_G+\lambda}{4} \frac{\partial V_{BB}}{\partial \lambda} + \frac{2-\lambda+2\lambda_G}{4} \frac{\partial V_{BG}}{\partial \lambda}. \tag{42}$$

Here again, the same argument applies: $V_{BG} - V_{GG} - 2c = 0$ when the equilibrium sex ratio is r_B^*, and so welfare is decreasing in λ.

We now turn to characterizing the welfare optimal allocation in society. We first investigate the conditions under which $\lambda = 0$ (i.e. having a balanced sex ratio) is welfare optimal. If $\lambda > 0$, then some parent with a girl is selecting for a boy. By doing so, the expected direct utility gain is $[U(1,1) - U(0,2) - 2c]$. In consequence, two additional boys are left unmatched, and the cost of this is at least $2[\rho(2) - \rho(1)]$. So under the condition of the proposition ($[U(1,1) - U(0,2) - 2c] - 2[\rho(2) - \rho(1)] < 0$), it is socially optimal to have $\lambda = 0$.

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Given that $\lambda = 0$ is welfare optimal, $\lambda_G = \lambda_B$. It is routine to verify that if $(U(2,0) - U(1,1) - 2c) + (U(0,2) - U(1,1) - 2c) > 0$, then optimality requires everyone exercising choice, while no one must exercise choice if the inequality is reversed.

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