The Demographic Consequences of Sex-Selection Technology*

Qi Li
University of Chicago

Juan Pantano
Washington University in St. Louis

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Abstract

Over the last several years highly accurate methods of sex selection before conception have been developed. Given that strong preferences for sex variety in offspring have been documented for the U.S., we move beyond bio-ethical and moral considerations and ask what the demographic consequences of sex-selection technology could be. Lacking variation across space and time in access to this technology, we estimate a dynamic programming model of fertility decisions with microdata on fertility histories from the National Survey of Family Growth. After recovering preferences for sex variety, we simulate the introduction of this technology. While this technology can reduce fertility by allowing parents efficiently reach their preferred sex mix, it could also increase fertility. This is because without this technology, many parents may opt not to have another baby given the uncertainty about its sex. Results suggest that these two effects operate simultaneously, but on net, sex selection technology ends up increasing the total fertility rate among married women.

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Extended Abstract

In the United States, many parents "keep trying" until they have a child of a specific sex. It is likely that underlying this quest are strong parental preferences for sex variety in their offspring. Many women who would ideally have had only one boy and one girl may end up with three or even four children of the same sex before eventually giving up. It is it is clear that from an economic perspective there is a friction, namely the uncertainty about sex at the time of conception, that may create significant welfare losses in the population at large. A less overt, more subtle phenomenon occurs, for example, when a mother of one, would like to enjoy this very same sex variety but decides not to go for a second child because it might end up being of the same sex as the first one. Here again, some welfare loss is associated with the uncertainty friction. In recent years, however, highly accurate methods of sex selection have been developed. Their use is of course subject to heated debate from a bioethical standpoint. However, if one puts aside, for the moment, issues of gender bias an resulting implications for the sex-ratio, one can view sex selection as a welfare improving technology that eliminates this "sex uncertainty" friction and allows parents to more precisely target the desired sex mix for their offspring.

In this paper we do not weigh in the debate on the morality of sex-selection technology but rather ask a simple positive question: what would be the demographic consequences of widely available, easily affordable sex-selection technology? This a simple question, but one that it is quite difficult to answer in an empirically convincing way. Previous work has tackled the question mostly at the theoretical level or using simulations under assumed rules of fertility behavior.[1] The main problem for a more credible evaluation comes from the lack of variation across time and/or space in meaningful exposure to the technology. Therefore a standard empirical strategy leveraging the behavioral differences among those who are exposed and those who are not, is not available. Moreover, even if variation in exposure/access existed it is not clear whether it would be exogenous. Finally, the short run impact of sex-selection technology might be very different from its steady state, long run impact. To tackle the question we develop a dynamic model of sequential fertility decisions that features explicit preferences for sex variety. We leverage the quasi-experimental variation inherent in the plausibly random determination of sex at the time of conception to identify the key structural

[1] Work in Demography, assuming somewhat rigid target fertility rules, has predicted substantial fertility declines in simulations of the consequences of sex predetermination. See for example, McDonald (1973), Markle and Nam (1971) and Sheps (1963). In economics, Ben-Porath and Welch (1976) and Samuelson (1985) were among the first to bring the issue to the attention of economists. Leung (1994) was among the first to address the issue empirically, using hazard models. Subsequently, Davies and Zhang (1997) described mechanisms by which sex-selection technology coupled with gender-biased preferences could lead to an increase in fertility.

parameter characterizing preferences for sex variety. We then estimate the model using a large sample of married couples from the National Survey of Family Growth who had no access to highly accurate, easily affordable and morally acceptable sex-selection method. Once the underlying preference structure is identified, we use the estimated model to conduct a simple counterfactual involving the introduction of a low cost and morally acceptable sex-selection technology. Our findings are somewhat surprising: this type of technology could lead to an *increase* in the total fertility rate among married women.

Our structural approach recovers heterogeneous preferences for number of children and sex variety. This knowledge allows us to endogenously re-compute fertility rules used by couples in counterfactual scenarios such as the one with sex-selection technology. Our approach has the potential to improve upon the traditional demographic approach, that directly poses an assumed fertility goal and simulates the resulting fertility that ensues as couples attempt to reach that goal with and without sex-selection technology.

Technology and Policy Background

Sex-Selection Technology. It is worth first getting some background on the technology of sex selection. Methods to select sex can be distinguished by whether they select before or after conception. The latter is usually more ethically objectionable. We discuss sex-selection before conception first. Several methods have been proposed to influence the likelihood of conceiving a child of a particular sex. These methods vary in their scientific basis and most of them are not deemed very reliable. They range from recommendations on the timing of intercourse during the woman's menstrual cycle[2], to the provision of acidic (or alkaline) environments for sperm[3], and even include a woman's diet[4]. A more invasive procedure involves injecting the woman with antibodies against Y- or X-bearing sperm.[5] Again, despite their plausible scientific basis, none of these methods have proven reliable.

The most effective, proven methods of sex-selection before conception involve sperm separation techniques followed by artificial intrauterine insemination (IUI) or *in vitro* fertilization (IVF) using a concentrated sperm sample that contains mostly X- or Y-bearing chromosomes. The first sperm separation technique was pioneered by Ronald Ericsson in the 1970s and involves a centrifugation or spinning of a sperm sample in a blood protein

[2]See Rorvik and Shettles (1970) who provide timing recommendations for couples seeking boys or girls. See also Whelan (1977) and James (1983)

[3]See Rorvik and Shettles (1970) who recommend acid (alkaline) douches when seeking a girl (boy).

[4]See Stolkowski and Choukroun (1981) who argue that a woman's diet may affect the consistency of her cervical mucus facilitating the passage of particularly kind of sperm. See also Warren(1985), Langendoen and Proctor (1982) and Lorrain and Gagnon (1975).

[5]See Bayles (1984) and Hull (1990).

solution. With rotation, the heavier spermatozoa (carrying an X chromosome) segregate themselves away from the lighter, Y-bearing sperm. The Ericsson method provides a substantial improvement over a 50-50 coin flip but it is far from perfect: Beernink, Dmowski and Ericsson (1993) report a success rate of approximately 70%. More recently, though, a new sperm separation technique has been developed. It is called MicroSort and uses a different technology: since X chromosomes have more DNA than Y chromosomes it is possible to identify them under laser light using a fluorescent material that attaches itself onto the DNA. Once the sperm carrying X and Y chromosomes has been labeled, a sorting procedure separates the X-bearing from the Y-bearing chromosomes, one by one. Early estimates indicated that MicroSort's technology would offer couples an 85% chance of conceiving a girl and a 65% chance of conceiving a boy. See Golden (1998). More recent estimates claim a success rate of up to 90% when seeking a girl and 75% when seeking a boy. The woman can then be artificially inseminated with the concentrated sub-sample of sperm carrying the desired chromosome. While these sperm separation techniques are not perfect, it is worth considering the possibility that they could be further perfected in the near future. At the time of this writing, the developers of MicroSort have not yet sought FDA approval for bringing this technique to market.

It is also possible to sex-select after conception. In this case one simply finds out the sex of the child that has already been conceived using some form of prenatal sex diagnosis, such as amniocentesis or ultrasound. A sex-selective abortion is then conducted whenever the developing pregnancy is of an unwanted sex.[6] Of course this method raises additional issues from a moral standpoint, especially when compared to methods that sex-select before conception. It is also difficult to implement, as ultrasounds for sex determination are usually performed at the 20th week and at that time it is usually too late to find a provider willing to conduct an abortion. Moreover, while attitudes towards abortion are fairly divided in the U.S., a clear majority opposes abortion when the only reason is undesired sex. While convincing estimates are hard to obtain, given implementation difficulties and strong public opinion opposition, sex-selective abortions are probably very rare in the U.S. and certainly less common than in India or China.[7]

Finally, an alternative method of sex-selection after conception (but before implantation)

[6] Most research on sex-selection technology has focused on the case of gender bias in contexts with more widespread use of sex-selective abortion. See for example, Leung (1994) for a hazard-based estimation of the effects of son-preference and sex-selection on fertility among chinese women in Malaysia. See also Leung (2011) for quantitative work on sex-selective abortion in the context of China's one-child policy.

[7] Some states (Illinois, Pennsylvania, Oklahoma and Arizona) have established bans on sex-selective abortion and a potential federal law has been recently debated in in the U.S. Congress. At the time of this writing, however, the federal ban seeking to criminalize sex-selective abortions has yet to pass the House of Representatives.

is in-vitro fertilization (IVF) followed by prenatal genetic diagnosis (PGD). PGD's primary role is to screen embryos for genetic abnormalities. But it can also be used to determine their sex. Then one can transfer embryos of desired sex only back into the uterus. While IVF+PGD is quite accurate, mechanical sperm separation followed by artificial insemination is arguably much less invasive and substantially less expensive. As a result, it has a much larger potential demand by typical couples.

Regulatory and Policy Background. The use of technology for sex-selection for non-medical reasons before conception is explicitly banned in several developed countries. No country explicitly permits sex-selection for non-medical reasons.[8] But in many developing countries, the legal status of this practice is not clear or well defined. Similarly, in the U.S. there is no official ban on the use of these methods, but relevant medical organizations such as the American Medical Association (AMA) and the American Society for Reproductive Medicine (ASRM) periodically discourage them through their ethical guidelines.

Given the lack of an explicit ban and despite discouragement from appropriate organizations, sex-selected babies for non-medical reasons are currently being born in the U.S. through both Ericsson's method and IVF+PGD. However, the phenomenon is not widespread due to issues of accuracy, invasiveness and cost. As explained above, while Ericsson's method is somewhat affordable and not very invasive, it is not that accurate. On the other hand, while IVF+PGD is highly accurate, it is quite invasive and extremely costly. It is likely that under the current, relatively lax regulatory framework, a perfected technology that simultaneously provides an affordable, minimally invasive and highly accurate sex-selection experience will have the potential for almost universal demand. The only remaining barrier for widespread adoption would at that point be only a moral or religious one. But again, a sex selection method that selects before conception tends to raise fewer issues on this dimension too. For example, some of the arguments made in support of bans against sex-selective abortions do not apply in this case. It is not far-fetched then to entertain a scenario in which such perfected technology generates a sex-selection demand boom and forces a more widespread discussion across society on the appropriate framework needed to regulate this type of procedure. Until then, the environment is likely to continue to be one of discouragement instead of explicit prohibition. For example, on the issue of sex selection before conception, the Council on Ethical and Judicial Affairs of the American Medical Association has stated that "sex selection of sperm for the purposes of avoiding a sex-linked inheritable disease is appropriate." At the same time, the Council suggested that "physicians should not participate in sex selection for reasons of sex preference" but "should encourage a prospective

[8] Israel has recently allowed it for families with extremely unbalanced sex-ratios (couples with 4 or more children of one sex and none of the other). See Siegel-Itzkovich (2005)

parent or parents to consider the value of both sexes."[9] Similarly the Ethics Committee of the American Society of Reproductive Medicine states that "preimplantation genetic diagnosis used for sex selection to prevent the transmission of serious genetic disease is ethically acceptable", but goes on to recommend avoidance of the procedure when solely used for sex-selection by stating that "...The initiation of IVF with PGD solely for sex selection ... should be discouraged".[10]

Data and Quasi-Experimental Evidence

To estimate our model we use data from the National Survey of Family Growth (NSFG). The NSFG, conducted by the National Center for Health Statistics, gathers retrospective information on the fertility histories of a random sample of women 15-44 years of age in the civilian, non-institutionalized population of the United States. In particular, for each woman, we have the year of birth and sex of each of her children.

We use the birth histories of married female respondents by the time of interview to recover the fertility choices each of these women made in each period (starting at age at marriage and leading up to the age at the time of the NSFG interview). The age at time of interview varies from 15 to 44 and therefore we have fairly complete histories for some of the oldest women in the sample and very short, censored histories for the youngest ones.[11] In addition to fertility histories, the NSFG also provides information on the completed level of education that these women have achieved by the time of interview. We use completed years of education by interview to classify NSFG women into low education and high education groups. The high education group includes women with at least some college. The low education group includes those who graduated from high school and high school dropouts. Since some women are too young at the time of interview to have completed their education, we restrict our sample to those who were 25 years of age or older at time of interview. Finally we use information on the pregnancy intention associated with each of the woman's reported births. We can distinguish among births that were intended and those that were unintended.

Our final estimation sample consists of 9930 married female respondents aged between 25 and 44 at the time of interview , using several NSFG waves spanning 1982-2008.[12] We focus on the subsample of married women who have been involved in a single marriage and

[9] See American Medical Association (1993)

[10] ASRM also discourages sex-selection when sex determination through PGD is obtained as a by product of PGD initiated for legitimate medical reasons.

[11] For simplicity, we organize the panel at the annual level, the unit of time to be used in the model we develop in the paper, as opposed to 9 months intervals, which is of course more accurate.

[12] The NSFG cycles included in our sample are NSFG 1982, NSFG 1988, NSFG 1995, NSFG 2002 and the first part of the NSFG 2006-2010 continuous wave.

Table 1: Completed Fertility by Time of Interview

	All Women	Women 40+		
		All Edu	Low Edu	High Edu
0	21.19	13.55	12.77	14.09
1	21.32	13.97	13.34	14.4
2	36.09	41.54	37.97	43.96
3	15.32	20.79	21.78	20.12
4	4.36	6.92	8.78	5.65
>=5	1.72	3.22	5.35	1.78
N	9,930	2,169	877	1,292

Note: Sample restricted to married women 25 and older at time of interview.
Pooled samples from NSFG waves 1982-2008

who remain married by the time of interview. We drop women who had a first live birth before the age of 16, those who had premarital births and those who have ever had multiple live births in a single year.

Table 1 presents the distribution of completed fertility by the time of interview. Column 1 shows numbers for the entire sample whereas columns 2, 3 and 4 are restricted to those who are at least 40 years old at the time of interview. These women are very unlikely to have additional births after the interview and therefore provide a better way of gauging the eventual patterns of completed fertility among NSFG women. Column 2 looks at all education levels, whereas columns 3 and 4 focus on subsamples of low and high education groups. Of course, the pattern of completed fertility among 40+ women are quite different from that in the entire sample. Mechanically, these women have had more time to have children and so the distribution shifts away from childlessness and low parities. Also, as well documented elsewhere, women with more education tend to have less children.

Table 2 shows the distribution of sex-specific completed fertility at the time of interview. As can be seen in the table, completed fertility follows a fairly symmetric pattern, an indication that sex bias is less apparent in the U.S. than in countries like India and China.

Another important difference between high and low education women is related to the timing of births. The distribution of age at first birth peaks at a much later age for highly educated women. The median age at first birth is 22 for the low education group and 27 for the high education group.

Table 2: Gender Specific Completed Fertility by Time of Interview

		Number of girls					
	nb	0	1	2	3	4	Total
Number of boys	0	14%	7%	9%	2%	0%	32%
	1	7%	21%	7%	1%		37%
	2	12%	8%	3%			22%
	3	4%	2%				5%
	4	1%					1%
	Total	37%	37%	19%	3%	0%	97%

Note: Sample restricted to women 40 and older at time of interview. Pooled samples from NSFG waves 1982-2008. Subsample includes those 97% of married women with 4 or less children at time of interview.

While there is no overt evidence of gender-biased preferences in the United States, Ben-Porath and Welch (1976) and Angrist and Evans (1998) document strong preferences for sex variety.[13] Consider women at parity $n = 2$ and define indicators SubsequentBirth_i and Same-Sex_i as follows

$$\text{SubsequentBirth}_i = \begin{cases} 1 \quad \text{if} & \begin{array}{l}\text{woman } i \text{ is observed to have} \\ \text{at least one more birth before interview}\end{array} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$\text{Same-Sex}_i = \begin{cases} 1 \quad \text{if} & \begin{array}{l}\text{the (two) children born so far} \\ \text{to woman } i \text{ are of the same sex}\end{array} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

A simple linear probability model for subsequent fertility (the observation of a third birth

[13] Rosenzweig and Wolpin (2000) lay out specific assumptions on preferences and household technology under which this type of empirical evidence can be interpreted as preferences for sex-variety.

Table 3: Subsequent Fertility and Sex-Composition

	(1)	(2)	(3)	(4)
First Two Children of Same Sex	0.0609***		0.0584***	
	(0.0128)		(0.0116)	
First Two Children are males		0.0749***		0.0661***
		(0.0152)		(0.0139)
First Two Children are females		0.0436***		0.0490***
		(0.0162)		(0.0146)
Age at second birth effects	No	No	Yes	Yes
Age at interview effects				
Observations	5709	5709	5709	5709
R-squared	0.004	0.004	0.185	0.185
Mean of Dep. variable	0.372	0.372	0.372	0.372

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

due to the same woman at some point before interview) is given by

$$\text{SubsequentBirth}_i = \alpha_0 + \alpha_1 \text{Same-Sex}_i + \varepsilon_i \tag{3}$$

Under some assumptions, Same-Sex$_i$ is as good as randomly assigned. Angrist and Evans present suggestive evidence of strong preferences for sex variety by showing that α_1 is positive, significant and sizable in magnitude. In words, couples are much more likely to be observed to have a third birth when the first two are of the same sex. Here we replicate Angrist and Evans' findings with our NSFG data. Table 3 presents the results. Column 1 presents the basic estimates while column 3 controls for age at second birth and age at interview effects. In both cases we find strong evidence of preferences for sex variety.

It is also possible to use the type of variation emphasized in Angrist and Evans' specification to test for gender bias. Define the following indicators

$$\text{All Boys}_i \quad = \quad \begin{cases} 1 \quad \text{if} & \begin{array}{l} \text{all children born (so far)} \\ \text{to woman } i \text{ are boys} \end{array} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

$$\text{All Girls}_i \quad = \quad \begin{cases} 1 \quad \text{if} & \begin{array}{l} \text{all children born (so far)} \\ \text{to woman } i \text{ are girls} \end{array} \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Now consider the modified linear probability model given by

$$\text{Subsequent Birth}_i = \alpha_0 + \alpha_b \text{All Boys}_i + \alpha_g \text{All Girls}_i + \varepsilon_i \tag{6}$$

Note that the relative magnitudes of α_b and α_g can be used to test for gender bias. In particular, if $\alpha_b \neq \alpha_g$, women prefer the sex with lowest α. Columns 2 and 4 of Table 3 present the results of the gender bias test. The coefficient α_b on All Boys$_i$ is larger than α_g, implying potential gender preferences in favor of girls (women are more likely to go for a third birth if they have had only boys). The magnitude of the difference is relatively large and indeed in Column 2 we reject that the 2 coefficients are equal. However, we fail to reject this null of "no gender bias" in Column 4, once we control for age at second birth and age at interview.[14]

While these results are interesting and useful in their own right, they don't allow us to predict the demographic consequences of sex-selection technology. Whenever a woman with two children of the same sex decides not to go for another child, we can't tell whether she would had gone for it, had the technology to secure its sex been available. In other words, for women who ideally would have liked to have one boy and one girl, but ended up having two children of the same sex, we cannot distinguish whether the decision not to go for a third child stems primarily from lack of strong preferences for variety or from the potential reduction in utility associated with having three children of the same sex, if the third child turns out to have the same sex as the first two.

To move forward, in the remaining of the paper we write an estimable model that incorporates the simplest possible structure needed to answer our research question: what would be the demographic consequences of widely available, easily affordable sex-selection technology? We then estimate the model using the fertility histories from NSFG and use

[14]The evidence for sex preferences in the U.S. is mixed. Dahl and Moretti (2008) find evidence that U.S. parents favour boys. Similarly, Almond and Edlund (2008) find son-biased sex-ratios in the US census. In contrast, Baccara et al (2012), using adoption data, find evidence in favour of girls. Behrman, Pollak and Taubman (1982) also find a slight parental preference for girls.

the estimated model to simulate the introduction of sex-selection technology. Our structural estimates allow for unobserved heterogeneity in preferences for sex variety and number of children. The estimated correlation in these unobserved preferences is critical to predict the impact of sex-selection technology. If those who care about variety also tend not to have very strong preferences for a large number of children the impact of introducing a sex-selection technology is more likely to be pronatalist. Indeed, our preliminary findings show that this technology ends up increasing the fertility rate in the long run, once all cohorts are exposed to the next technology. Our results stand in contrast to most of the literature in demography, which, by construction, tends to predict a decreased fertility following the introduction of sex-selection technology.

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