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ABSTRACT

Estimating the Effects of Expanding Ultrasound Use on Sex Selection in India*

The liberalization of the Indian economy in the 1990s led to an unprecedented increase in the availability of prenatal ultrasound technology. In this paper, we analyze the differential spread of ultrasound in India at the state level over a ten-year period (1999 to 2008) and the consequences for the prevalence of sex-selective abortion. Omitting the Southern Indian states, which had the fastest increase in ultrasound use and little sex selection, we find that higher levels of ultrasound use within a state are positively associated with the probability that a child is born male. This increased likelihood of having a male child is only found for children with no older brothers, i.e. births most likely to be affected by sex selection. The positive relationship between state-level ultrasound use and having a male child can be found across various subsamples: urban and rural, older and younger mothers, mothers with high and low education. The estimates are robust to including linear cohort-year time trends and prenatal health care controls.

JEL Classification: J13, J16, O1

Keywords: ultrasound, technology adoption, gender discrimination, son preference, sex-selective abortion, India

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1 Introduction

The liberalization of the Indian economy starting in the 1990s sparked an increase in ultrasound availability. Indian government data shows that the number of ultrasound machines manufactured in India increased rapidly between 1988 and 2003 with an especially marked increase after 1994 (George, 2006). In 1994, companies such as GE began partnering with local companies and producing ultrasound machines. In 2006, annual sales rose to $77 million (Wonacott, 2007). The cost of an ultrasound test in India is in the range of $10 to $20 (Ganatra and Hirve, 2002), and ultrasound has become easier to access even in many rural areas. Prior to ultrasound, amniocentesis and chorionic villus sampling were the only ways to test for the sex of a fetus. However, these methods are more expensive, more invasive, and riskier than ultrasound, and were not commonly used during pregnancies in India. Recent research attributes the rapid rise in sex selection in India during the 1990s to the introduction of ultrasound as a relatively cheap and safe way to determine the sex of a fetus (Arnold et al., 2002; Bhalotra and Cochrane, 2010). Research has also confirmed high levels of sex-selective abortions in India, causing an estimated half a million missing women in India per year (Jha et al., 2006, 2011; Bhalotra and Cochrane, 2010). There are different types of sex selection, such as infanticide or excess female mortality. As we focus on a technology that directly affects sex selection before birth, throughout our paper we use a narrower definition of sex selection: the abortion of female fetuses until a male child is born. This restricted definition is in line with earlier research ((Jha et al., 2011; Bhalotra and Cochrane, 2010).

To date, however, there is limited formal evidence on the effects of the continued spread of ultrasound technology on missing women in India. On the one hand, ultrasound can be misused for sex selection, exacerbating the already skewed sex ratio in India. On the other hand, ultrasound technology has legitimate medical benefits that may lead to general improvements in child and maternal health. Thus, it is essential to public health policy to identify whether there is a significant negative consequence of the increasing availability of ultrasound and to quantify such an effect if it exists.

This article provides a novel examination of the consequences of the increase in prenatal ultrasound use on sex selection in India. Our study quantifies the effects of an increase in ultrasound use on sex selection in two ways. We first examine the relationship between a mother's use of ultrasound during pregnancy and the sex of her child over time. Second, we analyze the relationship between changes in ultrasound availability over time at the state level, as measured by the average number of ultrasounds performed for firstborns in a given state over time. Previous research has documented that sex-selective abortion is not prevalent in the first pregnancy; however it increases with birth order (Jha et al., 2011; Bhalotra and Cochrane, 2010; Portner, 2010; Rosenblum, 2013). To reduce the possibility of bias from differential misreporting of ultrasound use for those who do and do not use ultrasound for sex selection, we only use the information on ultrasound use for these first pregnancies, where such bias would be unlikely. Furthermore, sex selection in India has only been found at higher parities if there is no older male sibling. Thus, to detect the effects of ultrasound expansion, we focus on sex outcomes for higher-order births conditional on having only older female siblings. To the best of our knowledge, this is the first article to estimate the effects of state-level ultrasound exposure on sex selection.

Our initial estimation demonstrates that while the mother's use of ultrasound during pregnancy is positively associated with the likelihood of having a son at birth, this relationship has diminished over time. The results of our analysis incorporating the state-level ultrasound exposure measures, however, show a more nuanced picture of the effects of ultrasound technology on sex selection. If all Indian states are included in the analysis, higher levels of ultrasound use within a state are negatively associated with the probability that a child is born male. However, this seemingly paradoxical finding is driven by the Southern Indian states that generally have greater gender equality, lower rates of sex selection, and the highest rates of ultrasound use. When these Southern states are omitted from the analysis, ultrasound use is positively associated with having a male child, especially among higher-order births with no older male siblings who are more likely to be subjected to sex selection. Furthermore, our analysis indicates that sex selection is significantly more prevalent in states classified in the third and fourth quartiles with regard to ultrasound exposure. We also find that sex selection at birth is more prevalent in households with more educated, older mothers living in urban areas. Higher ultrasound availability further exacerbates this practice among these groups, but also leads to increased sex selection for rural households, those with younger mothers, and where mothers have low levels of education. These results are consistently robust after controlling for state trends, state GDP changes over time, average antenatal care checkups, taking iron, and folic acid tablets during pregnancy, and tetanus vaccine usage.

This study makes several contributions. First, we contribute to the existing literature by being the first article to examine changes over time in individually reported ultrasound use and sex selection in India. For our analysis, we use the District Level Health Surveys (DLHS), the first nationally representative available dataset in India with enough observations to examine state-level changes in ultrasound use over time. Specifically, we use state-by-cohort variation in ultrasound use in India arising from the large-scale increase in ultrasound availability as a unique quasi-experiment. The number and location of ultrasound machines in India are unknown, thus the best proxy available for ultrasound availability is reported ultrasound use. We quantify the consequences of the increase in ultrasound use on sex selection in two ways. First, we examine the association over time between a mother's individual ultrasound use during pregnancy and the sex of her child. Second, we estimate the relationship between state-level trends in ultrasound use and sex selection.

2 Background

There is large body of research on son preference in India going back at least to Visaria (1969)'s analysis of the 1961 Indian census finding that female child mortality is substantially higher than male child mortality. Sen (1990) later brought more attention to this "missing women" problem. Research shows sons are preferentially given access to health care (Basu, 1989; Hazarika, 2000; Asfaw et al., 2007) leading to excess female mortality. Many parents in India follow son-preferring fertility stopping rules (Clark, 2000; Arnold et al., 2002), having children until a desired number of male children are born, which has discriminatory consequences for girls, exacerbating excess female mortality (Rosenblum, 2013). There is evidence that a relative increase in female wages may reduce excess female mortality in India (Rosenzweig and Schultz, 1982).

Like excess female mortality, sex selection is a major problem in India with estimates of the number of sex-selective abortions in the hundreds of thousands each year (Jha et al., 2006; Bhalotra and Cochrane, 2010). There are several recent articles examining the causes and consequences of sex selection. Ebenstein and Leung (2010), Ebenstein (2010), and Rosenblum (2017) show that economic incentives are likely a driving factor behind sex selection. Several articles find evidence that sex selection may reduce excess female mortality or increase the average health of non-aborted girls (Lin et al., 2008; Hu and Schlosser, 2015; Rosenblum, 2013; Anukriti et al., 2022). Bharadwaj and Lakdawala (2013) show that parents of boys in India are more likely to invest in prenatal care, indicating ultrasound is being used not only for sex selection but also for discrimination in prenatal care. Similarly, Almond et al. (2010) find that the introduction of ultrasound in China is related to prenatal discrimination against girls.

Given the prevalence of son preference, India has implemented several laws to address counteract discrimination against women and girls. For example, Kalsi (2017) finds that the introduction of reforms that required at least of third of local government positions to be reserved for women caused a reduction in sex selection. Bhalotra et al. (2020a) find that law changes in India giving women equal inheritance rights led to an intensification of son preference and sex selection. Rather than any specific policy change, we investigate the spread of a technology that facilitates sex selection.

Bhalotra and Cochrane (2010) show that the sharp increase in the Indian male-female sex ratio at birth coincides with the increased prevalence of ultrasound in the 1990s. A key difference between Bhalotra and Cochrane (2010) and our paper is that rather than looking at differences in the timing of the initial availability of sex selection, we quantify differences in trends in actual ultrasound use over time. In other words, our paper focuses on the spread of ultrasound use after the introduction of ultrasound, rather than looking at before and after the introduction of ultrasound itself. Hu and Schlosser (2015) take a related approach. They use the sex ratio at birth at the state-year level in India as a measure of the degree of sex selection to examine the effect of sex selection on child health outcomes. By contrast, we use the level of ultrasound use at the state-year level to examine the effect of the spread of ultrasound on sex selection itself.

Arnold and Parasuraman (2009) examine the relationship between reported ultrasound use and pregnancy outcomes using the 2005-06 Indian National Family Health Survey. They show that there is a positive correlation between a mother's individual ultrasound use and the probability a child is born male. If we ignore time trends, we find the same positive correlation between ultrasound use and sex selection. Our paper differs in that we investigate whether changes in state-level ultrasound use *over time* are associated with changes in sex selection. Our paper complements Chen et al. (2013) who investigate the effect of the spread of ultrasound availability on sex selection in China. They use the timing of the introduction of ultrasound machines at the county level in China and find that greater availability causes more sex-selective abortions. Unfortunately, such detailed data does not exist for India.

3 Data and Descriptive Statistics

We combine the 2002-2004 District Level Household Survey (DLHS II) and the 2007-2008 District Level Household Survey (DLHS III) to analyze the impact of the spread of ultrasound over time in India. The DLHS I data set is not used in the analysis because it does not report ultrasound use. These surveys were conducted by the Government of India through the International Institute for Population Sciences (IIPS). Both surveys are nationally representative at the district level and cover all of the approximately 600 districts in India. The DLHS II surveyed 507,571 ever-married women aged 15-44. The DLHS III surveyed 643,944 ever-married women aged 15-49.

Essential to the purpose of this paper, the DLHS II and DLHS III provide information on mothers' ultrasound use during their most recent pregnancy, which covers the years 1999 to

2008. To the best of our knowledge, these are the only years in which large-scale information on ultrasound use in India is available. Using this information, we create a measure of the availability of ultrasound for pregnant women at the state-year level. To simplify our analysis, we restrict the sample to children of birth order four or less.[1] Furthermore, since twins represent a different effect on the household compared to a singleton, we drop households with twins from the analysis. The resulting sample for the main analysis consists of 498,865 children born between 1999 and 2008.

The DLHS II and III ask demographic questions as well as detailed questions about fertility and childcare. The DLHS II includes full birth histories of mothers, while the DLHS III only includes details on children born since January 2004. Both surveys ask detailed questions about the most recently born child. In particular, they report whether an ultrasound test was used during the last pregnancy. Reporting rates for this question are close to 100 percent; thereby enabling us to construct state-level ultrasound exposure measures which are presumably exogenous to individual household behavior. As importantly, to reduce the potential bias from misreporting ultrasound use because it was used for sex selection, we only use the ultrasound data reported for first-borns since it has been extensively documented that there is no evidence of sex selection among first-born children.[2] Using our data, we find no evidence that there is a difference in sex outcomes for first pregnancies which used ultrasound and those that did not. The DLHS II reports ultrasound use regardless of the outcome of the pregnancy (live birth, abortion, stillbirth, or miscarriage), while the DLHS III reports ultrasound use except if the pregnancy ended in a miscarriage. To minimize reporting bias and to provide consistency between surveys, we only use ultrasound information if that pregnancy resulted in a live birth. All of our estimates are robust to calculating ultrasound exposure with data from the pregnancies that end in a live birth combined with the small fraction of pregnancies that do not end with live birth. Because the datasets only have information on ultrasound use between 1999 and 2008, our main estimates are restricted to this time range. This restriction effectively reduces the DLHS II full birth histories into birth histories similar to those reported in the DLHS III. Although the surveys do ask if a woman had an induced abortion for her most recent pregnancy, there are very few women who answer yes to this question and if they do answer yes, they do not report the sex of the aborted fetus or explain why they induced abortion. Thus, we follow the methodology of the recent research on sex selection by indirectly estimating sex selection through the observed number of males and females at birth.

We use reported ultrasound use of the most recent pregnancy in two ways. First, we directly estimate whether a mother's ultrasound use during pregnancy is correlated with the sex of her most recent child at birth. This approach could potentially be biased because there may be under-reporting of ultrasound use for parents who use ultrasound for sex-selective abortion. Furthermore, this approach only allows us to investigate the effects of ultrasound use on the subset of most recently born children. Last, it does not allow us to explore the geographic differences in the expansion of ultrasound use across India. In order to resolve these issues, our second ultrasound measure incorporates the ultrasound use for first-born children and calculates the average ultrasound use in a given year and state, plausibly exogenous to the individual and household behavior. We call this average state-year level of ultrasound use "ultrasound exposure" because it indicates the likelihood that ultrasound was used for a child born in that year and state even if we do not directly know whether ultrasound was used during that child's pregnancy. It also acts as a measure of ultrasound availability in a given state and can inform policymakers as to the consequences of expanding ultrasound access. This second approach, therefore, enables us to determine whether state-level trends in ultrasound use are associated with state-level trends in the sex ratio at birth.[3]

Table 1 shows descriptive statistics for the dataset. The mean values are separated by child-birth order in columns (1) through (4). As found elsewhere (Bhalotra and Cochrane, 2010; Ebenstein, 2007; Jha et al., 2011; Portner, 2010; Rosenblum, 2013), the proportion of male children at birth is close to biologically normal (51-52 percent) for first-borns and then rises for higher parities. Table 1 further demonstrates that mean ultrasound use is the same for first-born children regardless of sex. Therefore, we explore ultrasound use during the first pregnancy to construct the state-by-year ultrasound exposure measure we utilize in our analysis. Since better-off parents tend to have fewer children, parents' years of schooling are higher on average for lower-order births. For the same reason, scheduled caste and scheduled tribe households, as well as rural households, are more likely to represent parents of higher-order children.[4] Even though ultrasound usage is similar across first-borns regardless of sex, Table 1 reports a higher usage of ultrasound amongst male children of higher-order births compared to female children, indicating a positive relationship between ultrasound use and sex selection.

4 Estimation Strategy

4.1 Mother's Ultrasound Use

In this section, we first present an estimation equation to analyze the association between a mother's ultrasound use during pregnancy and the probability of having a male child for most recent births. Throughout, as the probability of having a son is close to fifty percent, the estimates use a linear probability model for ease of interpretation.[5] In particular, we estimate the following linear regression:

(1)

$$Y_{ijt} = \alpha + \beta_1 US_{ijt} + \beta_2 US_{ijt} * NOB_{ijt} + \beta_3 NOB_{ijt} + \gamma_t + \delta_j + \upsilon YOB_t * STATE_j + \pi' \mathbf{X}_{ijt} + \theta GDP_{jt} + \varepsilon_{ijt}$$

where the outcome, Y_{ijt}, is 1 if the most recently born child for mother i in state j and year t is male and 0 if female. US_{ijt} is a dummy variable that takes a value of 1 if the mother reported an ultrasound was used during her pregnancy. NOB_{ijt} are births of order two and higher when there is no older brother, the group of households with the highest potential to engage in sex-selective abortion and utilize ultrasound for this practice. A positive β_1 implies that sex selection is more likely to occur among mothers who use ultrasound during their pregnancy. On the other hand, β_2 captures the differential effect of ultrasound use on the sex selection of higher-order births without older brothers. The inclusion of the interaction term could help us to disentangle whether ultrasound has been used for sex selection or for its prenatal health benefits. If the ultrasound technology is merely utilized for its health benefits during pregnancy, the aforementioned interaction term should not be statistically significant, while a positive sig-

Table 1: Descriptive Statistics

	First-Born	Second-Born	Third-Born	Fourth-Born	All
	(1)	(2)	(3)	(4)	(5)
			Most Recently Born Children		
Ultra. Use, Male & Female	0.338	0.268	0.164	0.103	0.247
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	109380	107996	72506	44064	333946
Ultra. Use, Female Child	0.338	0.263	0.156	0.093	0.243
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Observations	51968	50075	32958	20275	155276
Ultra. Use, Male Child	0.339	0.273	0.171	0.112	0.250
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Observations	57412	57921	39548	23789	178670
			All Children		
Child is Male	0.519	0.523	0.528	0.523	0.523
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)
Ultrasound Exposure	0.229	0.224	0.188	0.159	0.210
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)
Mother's Years of Schooling	6.015	5.127	3.476	2.329	4.751
	(0.012)	(0.012)	(0.013)	(0.015)	(0.007)
Father's Years of Schooling	7.880	7.300	6.132	5.196	7.002
	(0.012)	(0.013)	(0.015)	(0.019)	(0.007)
Mother's Age at Birth	20.59	22.79	24.55	26.52	22.84
	(0.009)	(0.010)	(0.012)	(0.017)	(0.006)
Rural	0.728	0.741	0.784	0.815	0.755
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Hindu	0.772	0.771	0.752	0.729	0.762
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Muslim	0.117	0.119	0.138	0.161	0.128
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Christian	0.0557	0.0578	0.0638	0.0683	0.0596
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Backwards Classes	0.391	0.394	0.393	0.392	0.392
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)
Scheduled Caste	0.171	0.176	0.195	0.202	0.182
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Scheduled Tribe	0.155	0.161	0.187	0.206	0.170
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Observations	176048	157849	102688	62280	498865

Notes: Standard errors are reported in parentheses. In the analysis, we include variables for Sikh, Jain, and Buddhist. Because these groups represent less than three percent of observations, their means and standard errors are not reported here. Data source: DLHS II and DLHS III.

nificant coefficient would suggest increases in sex selection are elicited through increasing and cheaper access to ultrasound.γ_t are year of birth fixed effects to control for any general time trend in the sex ratio at birth that is common across India. δ_j are state-specific fixed effects, controlling for time invariant systematic differences across states. $YOB_t * STATE_j$ are state-specific linear time trends, to control for potential state-level time-varying factors such as changes in state-specific policies, social preferences, and law enforcement against ultrasound use in each state over time. $\mathbf{X}_{ijt}$ is a vector of household characteristics including the mother's and father's education, mother's age at birth, birth order dummy variables, caste, and religion dummies, and a rural dummy. GDP_{jt} refers to inflation-adjusted state-year level GDP per capita and accounts for the potential differences in economic development across Indian states over time. ε_{ijt} is a random, idiosyncratic error term. In all of our estimates, robust standard errors are clustered by state.

Southern states are not included in the main estimates as these are states that have largely avoided problems with sex-selective abortion and also invest more in health care resources than other regions of India. These states have seen a relatively large increase in ultrasound use during pregnancy at the same time as having little change in the sex ratio at birth. When estimated separately, there is no correlation between an individual or state-level ultrasound use and child gender in the Southern region. Thus, to keep the estimate focused on states where sex selection is indeed a substantial or potentially emerging problem and to avoid the Southern states substantially biasing the estimates, we omit them from the analysis. In other words, the Southern states are regions where increasing ultrasound use appears unproblematic and the remainder of this article will focus on understanding the locations where it may be detrimental to achieving a balanced sex ratio at birth.

Since sex detection is illegal in India,[6] one concern of this approach is that parents who use ultrasound for sex-selective abortion may under-report their ultrasound use. We only use responses about ultrasound use if there was a live birth afterward. Therefore, it is unlikely that the respondents are worried that the surveyor will think they used ultrasound for sex selection. However, it still may be the case that parents are less likely to report ultrasound use if they had used it for sex selection in the past. Moreover, Equation (1) assumes that controlling for observables, the error term ε_{ijt} is uncorrelated with the mother's ultrasound use. However, if mothers that use ultrasound technology for sex selection are systematically different from the rest of the population in unobservable ways, OLS estimations would be biased. Furthermore, these estimates may suffer from an endogeneity problem because parents likely demand ultrasound for sex selection, which could be the reason for a positive correlation between ultrasound use and a child being born male, especially among higher-order births without any older brothers. These concerns will be addressed in the next section when state-year level ultrasound exposure, as opposed to the mother's individual ultrasound use, provides a measure of the availability of ultrasound, which presumably has not been directly affected by household behavior.

4.2 State-Year Level Ultrasound Exposure

In this section, we describe our strategy for estimating the effect of the spread of ultrasound overtime on sex selection. This strategy exploits the plausibly exogenous state-by-cohort variation in average ultrasound use in India. We refer to the state-year mean ultrasound use as "ultrasound exposure". The proposed estimate of the average treatment effect of ultrasound exposure on the probability that a child is born male is given by β in the following baseline state and child's year of birth fixed effects equation:

(2)

$$Y_{ijt} = \alpha + \beta_1 US_{jt} + \beta_2 US_{jt} * NOB_{ijt} + \beta_3 NOB_{ijt} + \gamma_t + \delta_j + \upsilon YOB_t * STATE_j + \theta GDP_{jt} + \pi' \mathbf{X}_{ijt} + \varepsilon_{ijt}$$

where Y_{ijt} is 1 for a male child i (and 0 for a female child) born in state j in year t, and now includes all children in the data born between 1999 and 2008 (which we refer to as the "2000s"). US_{jt} is the measure of ultrasound exposure in state j in year t. The other variables are the same as in Equation (1).

A potential confounding factor for the estimation of Equation (1) is systematic reporting bias. In an effort to circumvent this potential concern, we exclusively focus on firstborns in the construction of the state-level ultrasound exposure measure since as shown in the literature reporting bias would be limited if any for the firstborn. We also limit our analysis to live births, which further decreases the propensity to under-report ultrasound utilization. In addition, since we include state-fixed effects in our analysis, if under-reporting rates are similar over time in the same state, this under-reporting will not affect our estimates. Similarly, if there is a nationwide change in the reporting of ultrasound use over time, such change will be absorbed by the year-fixed effects we include in our analysis. However, our results will be confounded if state-level trends in sex selection are correlated with state-level trends in misreporting of ultrasound use. This problem should be mitigated by the fact that the proportion of pregnancies that end in sex selection represents a small number of total pregnancies as well as the large variation in average reported ultrasound use across Indian states. Nevertheless, we also control for linear state trends in our analysis to formally account for the aforementioned concern.

A related concern is the potential for differences in law enforcement against sex-selective abortion. Sex detection has been illegal in India since the passage of the Pre-Natal Diagnostic Techniques Act of 1994 (and put into effect in 1996). However, even though sex determination is illegal all over India, some states may be differentially enforcing laws against sex selection. In states with a rapid increase in ultrasound use, the government may be putting more resources into combating sex selection, and, thus, allowing a relative rise in sex selection in states with a slow increase in ultrasound use.[7] Our estimates that include linear state-cohort trends also address this potential concern.

An additional potential challenge for the interpretation of our analysis is omitted variables bias, that something else, like economic development, is increasing the demand for ultrasound and lowering the demand for sex selection. State and year fixed effects eliminate state-level time-invariant omitted variables and omitted variables that impact India in the same way over time. To help to account for differentially time-varying omitted variables, we control for state-level GDP per capita and, in one robustness test, access to other prenatal health resources.

5 Estimation Results

5.1 Overview of Ultrasound Use and Sex Selection

One may expect that the spread of ultrasound use across India would exacerbate sex-selective abortion. This no doubt happened in the 1990s, as shown by Bhalotra and Cochrane (2010). However, after the initial burst of sex-selective abortion in the 1990s, it is not clear that the increasing availability of ultrasound in Indian states will increase the incidence of sex-selective abortions in states where ultrasound machines are already available. Because only a small percentage of the population uses ultrasound for sex selection, it is possible that only a small amount of ultrasound availability is required to satisfy the demand for sex detection. Beyond this level, the greater availability of ultrasound could potentially have little effect on sex selection. Therefore, given the health benefits of ultrasound technology and increasing usage, it is of interest to more directly document the potential sex selection effects of ultrasound availability for better future public health policies.

The unadjusted association between the spread of ultrasound use and sex selection can be seen from graphs constructed from the DLHS II and III. Figure 1 shows the diffusion of ultrasound use by region and year of birth.[8] Each data point indicates the percent of the pregnancies where ultrasound was used for the most recent, first-born pregnancies in a given region year. Ultrasound use has spread most quickly in the south, north, and west of India. Northern India has the highest male-female sex ratio in India and ultrasound use rose from 14 percent in 1999 to 40 percent in 2008. Western India also has a highly skewed sex ratio at birth and ultrasound use increased from 29 percent in 1999 to 48 percent in 2008. However, Southern India, which generally has a relatively balanced sex ratio, exhibited the most rapid increase in ultrasound use, growing from 26 percent in 1999 to 77 percent in 2008. The other regions of India saw modest increases in ultrasound use, rising from 5-8 percent in 1999 to 10-13 percent in 2008.

For an overview of patterns in sex selection, we examine the sex ratio at birth with the sample separated into regions with fast ultrasound expansion (north, west, and south) and slow ultrasound expansion (center, northeast, east). We further restrict the sample to children at a

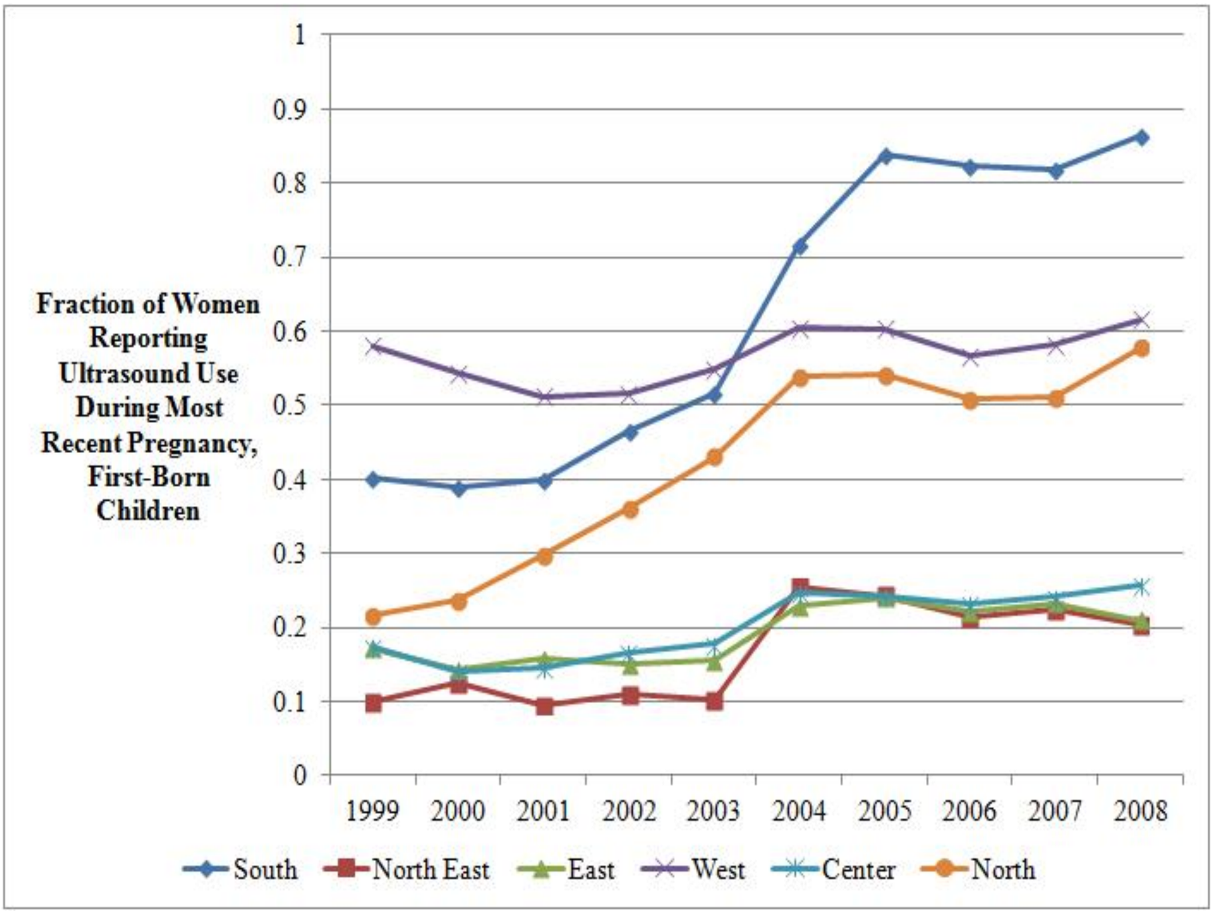

Figure 1: Fraction of women reporting ultrasound use during most recent pregnancy, adjusted by survey weights. Only first pregnancies and those that resulted in live birth are included. Data Source: DLHS II and DLHS III.

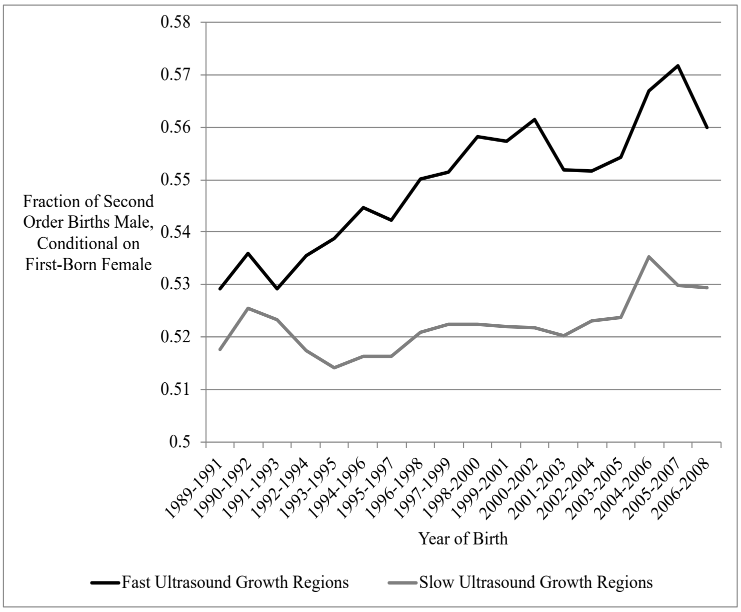

Figure 2: Gap in the sex-ratio at birth in regions with fast versus slow growth in ultrasound exposure. Three-year smoothed averages. Fast growth regions are the North and West (South omitted). Slow growth regions are the Center, Northeast, and East. Data Source: DLHS II and DLHS III.

high risk of sex selection: second-born children who have a first-born sister.[9] Figure 2 demonstrates the sex ratio at birth for these children from 1989 to 2008, divided into the fast and slow ultrasound-growing parts of India. The data is smoothed over three-year averages. Sex selection has been rising over time in both regions. The pattern shows a gap between the slow and fast ultrasound growth regions starting in the early 1990s, but that gap begins to close in the 2000s. Sex selection appears to have leveled off in the fast growth regions, while it is increasing in the slow growth regions.

5.2 Individual Ultrasound Use

In this section, we first present the results estimating the association between a mother's ultrasound use and the sex ratio at birth. Our initial estimates show that while a mother's ultrasound use during pregnancy is positively associated with sex selection before birth, this correlation has been weakening over time. The estimation results for Equation (1) are reported in Table 2. Similar to earlier studies, in column (2) we demonstrate that ultrasound use for firstborns is not associated with the gender of newborns; thereby providing supporting evidence for exclusively focusing on the reported ultrasound use for firstborns in constructing state-year ultrasound exposure measures. In columns (3) and (4), we focus on children of birth order 2 to 4 since this group is potentially subject to sex-selective abortion, especially when there is no older brother. Column 3 shows that a mother's ultrasound use is correlated with a 2 percentage point increase in the probability that a child is born male. Column 4 includes an indicator for having no older brother's variable and its interaction with ultrasound use. In line with the evidence of where sex selection occurs, children with no older brothers are about 4 percentage points more likely to be male. In addition, if ultrasound was used during the pregnancy and there were no older brothers, the probability of being born male more than doubles. Thus, we find a positive relationship between individual ultrasound use during pregnancy and the likelihood of having a male child, but only for children with no older brothers. These estimates omit the Southern region for which there is no statistically significant relationship between ultrasound use and the probability a child is born male. Including them would reduce the estimated coefficients in columns (1), (3), and (4).

5.3 State-Year Ultrasound Exposure and Sex Selection: Main Specification

In this section, we evaluate the association between state-birth year ultrasound exposure measures and sex ratio at birth. As aforementioned, this measure of ultrasound availability is plausibly exogenous to individual and household behavior and could better capture the association

Table 2: Individual Ultrasound Use and Probability of a Male Birth

	Birth Order 1-4	Birth Order 1	Birth Order 2-4	
	(1)	(2)	(3)	(4)
Ultrasound	0.012***	0.004	0.020***	-0.004
	(0.004)	(0.004)	(0.005)	(0.005)
No Older Brother				0.044***
				(0.005)
Ultrasound * No Older Brother				0.054***
				(0.008)
Observations	282825	90562	192263	192263
Household Variables	Yes	Yes	Yes	Yes
State and Year Fixed Effects	Yes	Yes	Yes	Yes
State-Year Linear Trends	Yes	Yes	Yes	Yes

Notes: Robust standard errors, clustered at the state level, are reported in parentheses. Column (1) is the estimate for the sample of most recent births of birth order 1 through 4. Column (2) is the estimate for the sample of firstborns. Columns (3) and (4) are estimates for the sample of most recent births of birth order 2 through 4. Household variables: mother's years of schooling, father's years of schooling, mother's age at birth, birth order dummies, a rural dummy, religion and caste dummy variables, and constant state-level GDP in the year of birth. The Southern region is omitted. Data Source: DLHS II and DLHS III and Government of India Ministry of Statistics and Programme Implementation.
(* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$)

between access to ultrasound technology and sex selection. Furthermore, these estimates include a substantially larger sample, as the previous estimates only focused on the sample of more-recent pregnancies for which individual ultrasound use is recorded in the surveys. Results from estimating Equation (2) are presented in Table 3. Similar to Table 2, we first present the point estimates for children of birth order 1 to 4 in column (1). In contrast to the individual-level estimates, there is no overall statistical relationship between ultrasound exposure and the probability of having a male child when first-borns are included. In column (2), we focus on the sample of first-borns, with estimates consistent with the individual level results demonstrating no evidence for sex selection in first births. In the last two columns of Table 3, we present the estimation results exclusively for children with second and higher birth orders since this group is more likely to engage in sex-selective abortion, especially in the presence of no older brothers. Even though in column (3) we continue to find that increased availability of the ultrasound technology does not seem to lead to a skewed sex ratio in general for higher order births, column (4) of our results now points to an important heterogeneity in response to ultrasound exposure. We find that the likelihood of having a male child at birth increases by approximately one percentage point if a child has no older brothers. As we find in the individual-level estimates, the interaction term for no older brothers and ultrasound exposure reveals a statistically significant and positive point estimate suggesting that higher levels of ultrasound availability could be associated with a skewed sex ratio at birth if the child has no older brothers and was born in a state with a higher ultrasound exposure measure. To put the coefficient in context, setting the ultrasound exposure measure to the average across India (26.5), implies about a 1.7 percentage point greater likelihood of having a male child for birth orders two to four. This is a large association, given that a small percentage of total pregnancies end in sex-selective abortion.

We examine the potential for non-linearity in the effect of ultrasound exposure on sex selection in Table 4 by replacing the continuous exposure variable with binary ultrasound exposure quartiles. There is no statistically significant relationship between the different quartiles and the probability of a male birth. However, when interactions with having no older brothers are included in column (4), it is apparent that the effects of ultrasound exposure increase with each quartile, with the largest and most statistically significant relationship occurring in the 4th quartile. As expected, having no older brothers increases the probability of children being born male.

Table 3: State-level Ultrasound Exposure and Probability of a Male Birth

	Birth Order 1-4	Birth Order 1	Birth Order 2-4	
	(1)	(2)	(3)	(4)
Ultrasound Exposure	-0.0193	-0.0361	-0.0121	-0.0350
	(0.0225)	(0.0273)	(0.0295)	(0.0307)
No Older Brother				0.0105**
				(0.0046)
Ultrasound Exposure*No Older Brother				0.0657***
				(0.0145)
Observations	432621	148287	284334	276181
Household Variables	Yes	Yes	Yes	Yes
State and Year Fixed Effects	Yes	Yes	Yes	Yes
State-Year Linear Trends	Yes	Yes	Yes	Yes

Notes: Robust standard errors, clustered at the state level, are reported in parentheses. Column (1) is the estimate for the sample of children born of birth order 1 through 4. Column (2) is the estimate for the sample of firstborns. Columns (3) and (4) are estimates for the sample of births of birth order 2 through 4. Household variables: mother's years of schooling, father's years of schooling, mother's age at birth, birth order dummies, a rural dummy, religion, and caste dummy variables, and constant state-level GDP in the year of birth. The Southern region is omitted. Data Source: DLHS II and DLHS III.
(* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$)

5.4 State-Year Ultrasound Exposure and Sex Selection: Heterogeneity and Robustness

We have shown that ultrasound exposure is positively associated with sex selection in children with higher birth orders without older brothers, while it has no or limited effect on sex at birth in the population at large suggesting that it has also been utilized for its prenatal health benefits. However, it is of interest to quantify the heterogeneous effects of ultrasound exposure on sex selection among different fractions of the population. In Table 5, we present the heterogeneous

Table 4: Ultrasound Exposure Quartiles and Probability of a Male Birth

	Birth Order 1-4	Birth Order 1	Birth Order 2-4	
	(1)	(2)	(3)	(4)
2nd Quartile Ultrasound Exposure	-0.0000	-0.0019	0.0012	-0.0020
	(0.0022)	(0.0050)	(0.0019)	(0.0036)
3rd Quartile Ultrasound Exposure	-0.0025	-0.0066	-0.0002	-0.0074
	(0.0038)	(0.0069)	(0.0048)	(0.0056)
4th Quartile Ultrasound Exposure	-0.0049	-0.0045	-0.0056	-0.0177*
	(0.0059)	(0.0081)	(0.0076)	(0.0086)
N.O.B.				0.0166***
				(0.0058)
2nd Quartile Ultrasound Exposure*No Older Brother				0.0097
				(0.0079)
3rd Quartile Ultrasound Exposure*No Older Brother				0.0186*
				(0.0095)
4th Quartile Ultrasound Exposure*No Older Brother				0.0315***
				(0.0073)
Observations	432621	148287	284334	276181

Notes: Robust standard errors, clustered at the state level, are reported in parentheses. Ultrasound exposure between 0 and 10 percent is the omitted category. Children are birth order 4 or less. Additional controls: father and mother's years of schooling, state and year of birth fixed effects, mother's age at birth, birth order (except column 2), rural, religion, caste, and state-year level GDP per capita in constant 1999-2000 rupees. Data Source: DLHS II and DLHS III.
(* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$)

effects of ultrasound exposure on sex outcomes at birth. All columns in Table 5 mimic our preferred specification reported in column (4) of Table 3 which includes an indicator for having no older brothers and the interaction of this indicator with state-level ultrasound exposure. In columns (1) and (2) of Table 5, we split the sample into rural and urban populations, respectively. When we exclusively focus on the rural population, the point estimates and statistical significance are similar to the baseline specification.

The analysis of the urban population reveals a negative relationship between ultrasound exposure and the probability of a male birth. Sex selection itself is a more severe problem in urban areas, as can be seen by the substantially higher coefficient for having no older brothers. The coefficient for the interaction term is more weakly associated with higher rates of male births, although of similar magnitude as in rural households. Since ultrasound diffusion went from urban to rural parts of India (Khanna, 1997), it is possible that urban areas across India already had a high enough ultrasound availability to satiate demand for sex selection in the 1990s, and thus we would not observe as strong a change in the 2000s. Thus, a large part of the rise in sex selection in India in the 2000s may have been occurring in rural areas that more recently got access to ultrasound. The negative coefficient on ultrasound exposure for urban households may be an indicator of this kind of non-linearity in ultrasound exposure effects.

In columns (3)-(6) we allow the ultrasound effects to vary by mothers' characteristics. Doctors are likely to suggest ultrasound be used if a pregnancy is risky. The risk of pregnancy increases with the age of the mother; therefore, they are more likely to use ultrasound for health reasons rather than sex-selective abortion. On the other hand, older parents may have a higher incentive to resort to sex selection when there are already potentially several other children and fewer years of potential fertility. To investigate this potential difference in ultrasound use, in column (3), the subsample is restricted to mothers who were age 30 or older at the time of birth, while in column (4) the subsample is restricted to mothers who were under age 30 at the time of birth.[10] The estimated coefficient for having no older brothers in column (3) is twice the magnitude of our full estimates as well as in the younger mothers subsample in column (4), indicating more evidence of sex selection in general for older mothers. The interaction term remains similar in magnitude in both young and older mother samples, indicating little difference in the effects of ultrasound exposure on young versus old mothers and, if anything, more of an effect on older mothers.

With the rapid economic development of India during the 1990s, ultrasound became widely available to households that had no or limited ex-ante access. Therefore, it is possible that ultrasound exposure has the largest effect among disadvantaged households, proxied here by mothers without any schooling. We restrict the sample to mothers with zero years of education in Column (5) and eight or more years of education in Column (6). In accord with previous findings, our results demonstrate that more educated mothers are more likely to engage in sex selection in general as indicated by the large, statistically significant coefficient for no older brothers. However, both education groups have positive and statistically significant coefficients on the interaction term between having no older brothers and ultrasound exposure, while the estimated effect is larger for educated mothers.

Last, in column (7) we include state-year measures of additional forms of prenatal care to test whether our results are being driven by omitted prenatal health care variables. Here we include state-year average reported use of antenatal care checkups, use of iron or folic acid tablets, receiving a tetanus vaccine while pregnant, and delivery in a hospital. The positive relationship between ultrasound exposure and sex selection for higher order births with no older brothers remains virtually unchanged when these additional prenatal care variables are included; suggesting that our results are not an artifact of additional prenatal care indicators suggesting that for higher order births without older brothers the increasing ultrasound availability in a given state results in a gender imbalance in favor of boys. Taken together, our analysis provides suggestive evidence on the heterogeneity of the estimated ultrasound exposure effects on sex ratio at birth. More specifically, we find that more educated, older mothers residing in urban areas are more likely to have sons in their second or later births which is indicative of sex selection and this sex imbalance is further exacerbated in states with high ultrasound availability.

Table 5: State-level Ultrasound Exposure and Probability of a Male Birth: Heterogeneity and Robustness

	Rural	Urban	Mother Age ≥ 30	Mother Age < 30	Mothers 0 Years Education	Mothers 8+ Years Education	Prenatal Health Care
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Ultrasound Exposure	0.0109	-0.1352**	-0.0111	-0.0512	-0.0240	-0.0212	-0.0364
	(0.0301)	(0.0581)	(0.0512)	(0.0348)	(0.0418)	(0.0596)	(0.0316)
No Older Brothers	0.0115**	0.0275***	0.0263**	0.0111**	0.0014	0.0460***	0.0140***
	(0.0052)	(0.0079)	(0.0111)	(0.0043)	(0.0053)	(0.0079)	(0.0049)
Ultrasound Exposure*No Older Brothers	0.0635***	0.0558*	0.0702*	0.0626***	0.0461**	0.0621**	0.0672***
	(0.0169)	(0.0278)	(0.0344)	(0.0128)	(0.0185)	(0.0261)	(0.0144)
Observations	214612	61569	62479	213702	141916	75293	275680

Notes: Robust standard errors, clustered at the state level, are reported in parentheses. Children are birth order 2 to 4. All estimations include control variables for mother's age at birth, birth order, religion, caste, rural/urban dummies (except for columns 1 and 2), child year of birth fixed effects, state fixed effects, state-year linear trends, and state GDP per capita in the year of birth. For Prenatal Health Care in column (7), we include variables for state-year level averages of antenatal care checkups, use of iron or folic acid tablets, receiving a tetanus vaccine, and delivery in a hospital.
(* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$)

6 Discussion and Conclusion

In this article, we provide causal evidence of the potential consequences of ultrasound availability on sex selection in India. Specifically, we use state-by-cohort variation in ultrasound use in India arising from the large-scale increase in ultrasound availability as a unique quasi-experiment. We quantify the consequences of the increase in ultrasound use on sex selection in two ways. First, we examine the association over time between a mother's individual ultrasound use during pregnancy and the sex of her child. Second, we estimate the relationship between state-level trends in ultrasound availability proxied by the average ultrasound use for the firstborns in a given state over time and the sex ratio at birth. For our analysis, we use the District Level Health Surveys (DLHS), the first nationally representative available dataset in India with enough observations to examine state-level changes in ultrasound use over time.

When the Southern states are omitted from the analysis, ultrasound use is positively associated with having a male child, especially among higher order births with no older male siblings which are more likely to be affected by sex selection practices. Our analysis also illustrates that sex selection is significantly more prevalent in states categorized within the third and fourth quartile of ultrasound exposure. Further, these results are robust to a battery of alternative specifications including controlling for linear state trends, state GDP over time, averages of antenatal care checkups, use of iron or folic acid tablets, receiving a tetanus vaccine, and delivery in a hospital. In the higher order of births where there is no older son, sex selection is more common among educated and urban mothers who were 30 years of age or older at the time of the birth.

Taken together, our analysis underscores the importance of rigorous empirical analysis with careful consideration of the nuanced effects across states and localities to achieve desired public health outcomes. Our findings further demonstrate that not only the availability of ultrasound technology but the demand for sons and attitudes favoring sons are collectively contributing to the adverse effects of ultrasound technology on the sex selection. It does not seem like a feasible or enforceable policy to limit the provision of ultrasound machines or strengthen regulation of their use. Rather, the incentives and social norms that lead to son preference must be addressed. This could include conditional cash payments to households with daughters, which already exist in some parts of India.[11] However, given that sex selection is more of a problem among the more educated and, presumably, high-income households, it will be difficult for policy to address the economic incentives causing son preference. For example, there is a substantial problem of large dowry payments from daughters' parents to their son-in-law's household (Bhalotra et al., 2020b), which are already illegal. The government may not be able to fully compensate parents of only daughters for the lack of retirement security that sons provide, particularly in the context of low levels of female labor force participation. Even if economic incentives could be adequately adjusted, it may not reverse persistent non-economic social norms around son preference. Nonetheless, India should anticipate the increasing prevalence of sex selection, particularly in states just starting to get access to higher levels of ultrasound, and target its policies to those locations.

Sex selection continues to pose significant threats to the gender imbalance in India. Findings in this article shed light on the potential consequences of ultrasound technology on birth outcomes and demonstrate significant heterogeneity in its use. On the one hand, evidence from the Southern states illustrates that the rapid spread of ultrasound in some parts of India is unlikely to further exacerbate the sex selection problem in those areas. Thus, the possibly significant health benefits of greater access to ultrasound do not need to be balanced with a fear of increasing misuse. On the other hand, our findings demonstrate that the increasing availability of ultrasound technology is associated with an elevated prevalence of prenatal sex selection in the rest of India; thereby suggesting that demand for sex selection could be an important contributor to the misuse of ultrasound technology. Overall, even though the availability of ultrasound technology exacerbates the sex imbalance at birth, our findings indicate that the reasons for sex selection are likely far more complicated than the simple spread of sex-detection technology.

Notes

[1]All of our main estimates are robust to including all children.

[2]We also note here that our results remain statistically and quantitatively similar when the state-level ultrasound exposure measure is constructed using all births.

[3]We do not use district-level measures of ultrasound exposure as the limited number of observations at the district-year level (there were approximately 600 districts in India over the time period of interest) creates too much noise in the estimated level of ultrasound exposure, making statistical inference difficult.

[4]Higher older children may be more likely to live in states with less access to health services, including ultrasound. We control for these possibilities in our estimates by including household demographic characteristics, birth order dummies, and state fixed effects.

[5]Estimation results are robust to using a logit or probit specification.

[6]Getting an ultrasound test is not illegal. It is illegal for the doctor or technician to reveal the sex of a fetus to parents.

[7]Nandi and Deolalikar (2013) find that the earlier implementation of laws against sex-detection in Maharashtra reduced sex selection there relative to the nearby parts of India that later introduced such laws. Maharashtra passed laws against sex detection in 1988, whereas the Pre-Natal Diagnostics Technique Act (PNDT) was implemented nationally in 1996 and later amended as the Pre-Conception and Pre-Natal Diagnostic Techniques Act (PCPNDT) in 2004. However, Portner (2010) finds that the PNDT was ineffective at reducing sex selection. Public Health Foundation of India (2010) argues that the acts were essentially unenforced with approximately 20 convictions out of 600 cases filed under the PNDT and PCPNDT through 2009.

[8]North = Delhi, Haryana, Himachal Pradesh, Punjab, Rajasthan, and Uttaranchal/Uttarakhand. Center = Uttar Pradesh and Madhya Pradesh. West = Gujarat and Maharashtra. South = Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu. East = Bihar, Chhatisgarh, Jharkand, Orissa, and West Bengal. Northeast = Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Sikkim, and Tripura.

[9]There is no difference in the sex-ratio between regions if the first-born child is male.

[10]Mothers aged 35 and older are generally more closely monitored during their pregnancy due to increased risk of complications. Since the vast majority of mothers in our sample completed their fertility before age 35, we use age 30 as a risk cut-off rather than age 35.

[11]For example, the Ladli Social Security Allowance Scheme in Haryana provides cash payments to parents with only daughters once any parent reaches the age of 45.

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A Appendix (Intended for Online Supplementary Material): Indian Census Graphs

In this section, we present state-level graphs grouped by region for the number of females per 1000 males, aged 0-6, from 1991, 2001, and 2011 Indian Censuses. For comparison, sex ratios at birth in developed countries are in the 950-975 range, which rises as children age because boys are more likely to die at young ages than girls (assuming equal care). In the United States 2010 Census, there were 958 females per 1000 males for children under age 5. Many of the states of India are close to this reference group, with most exceptions being in the north, center, and west. The census sex ratios reflect both the effects of sex-selective abortion and excess female mortality, and thus the more specific estimates of child sex at birth in this paper are a better measure of the effect of ultrasound use on sex selection. Nevertheless, the census data is as accurate as one can get for an estimate of the actual sex ratio in India and represents the trends in the overall demographic outcomes of the Indian population.

North India, albeit experiencing large drops in the number of girls from 1991 to 2001, shows little change in the number of females from 2001 to 2011. If anything, most of the states show improving sex ratios over the last ten years even with an almost quadrupling of reported ultrasound use. Child sex ratios in south India have generally remained flat over the three censuses, even though it is the region with the largest increase in ultrasound use. The east and northeast have several states showing a worsening trend in child sex ratios over time, and yet they have only had modest increases in ultrasound use.

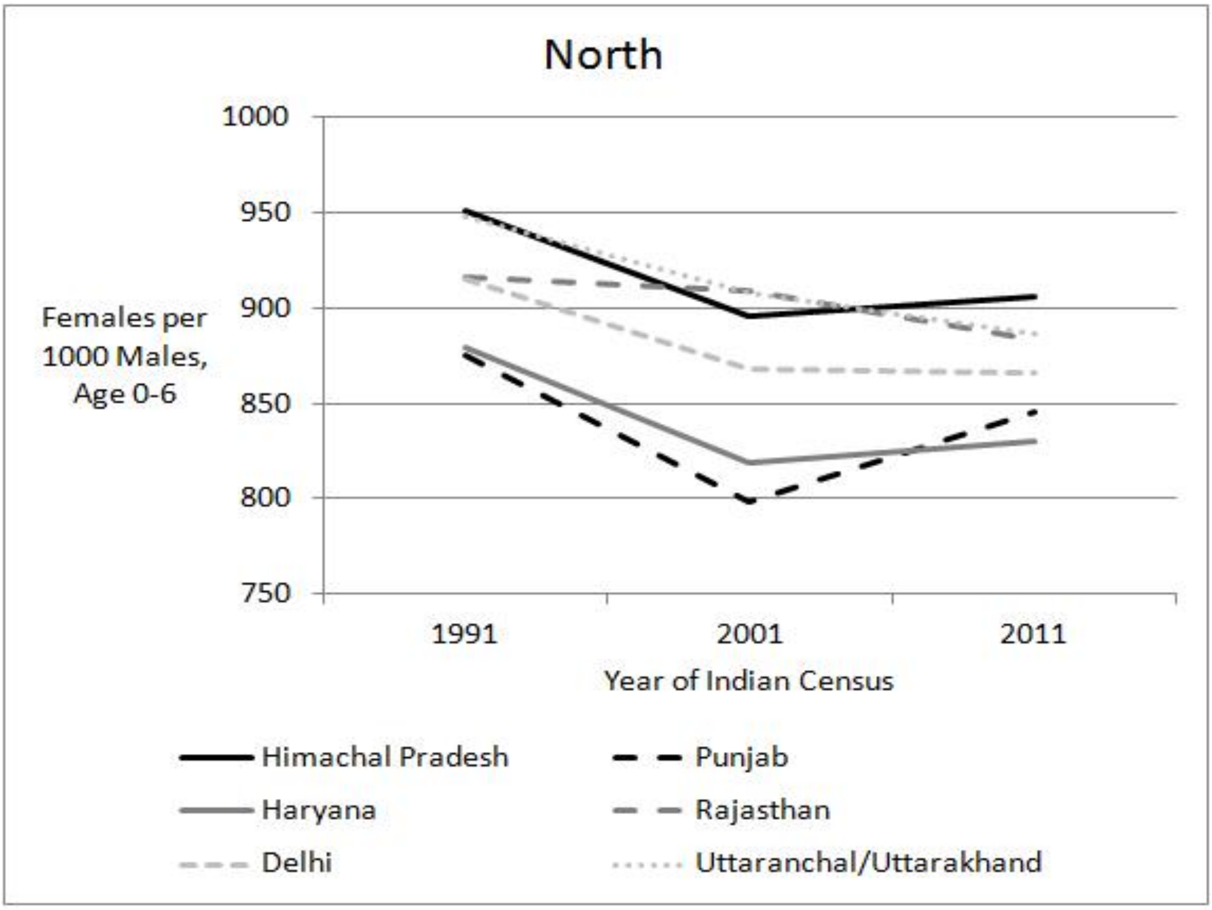

Figure 3: Child Female-Male Sex Ratio: North. Data Source: Indian Census 1991, 2001, and 2011.

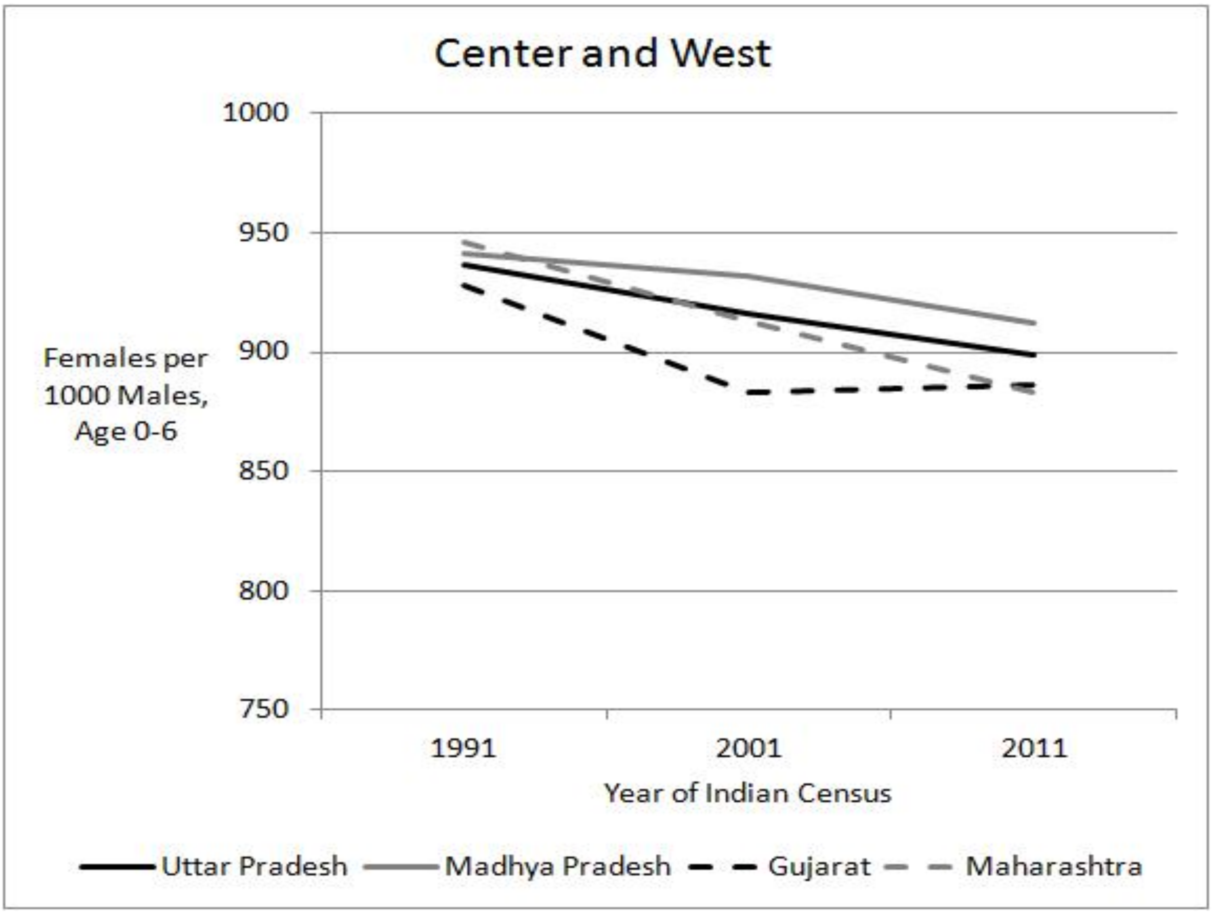

Figure 4: Child Female-Male Sex Ratio: Center (solid lines) and West (dashed lines). Data Source: Indian Census 1991, 2001, and 2011.

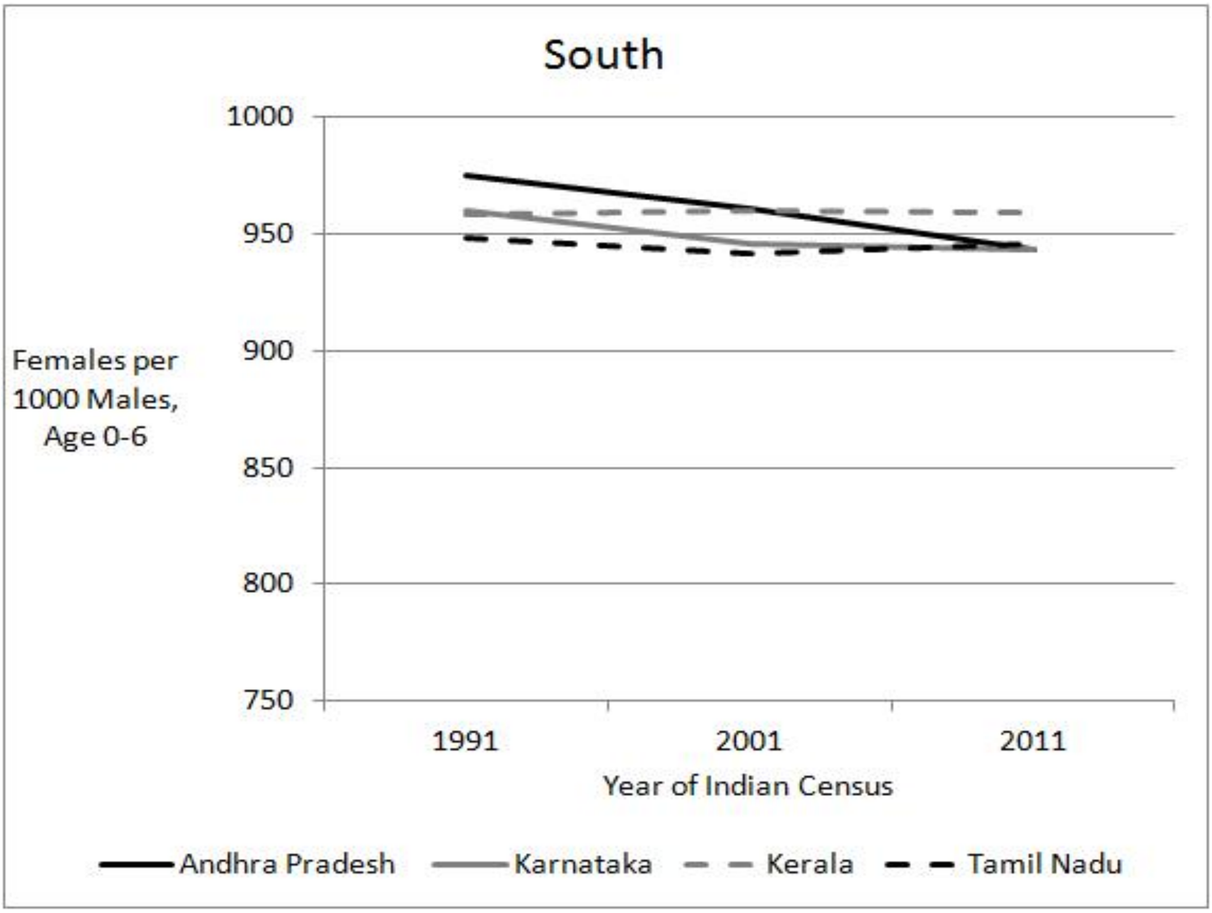

Figure 5: Child Female-Male Sex Ratio: South. Data Source: Indian Census 1991, 2001, and 2011.

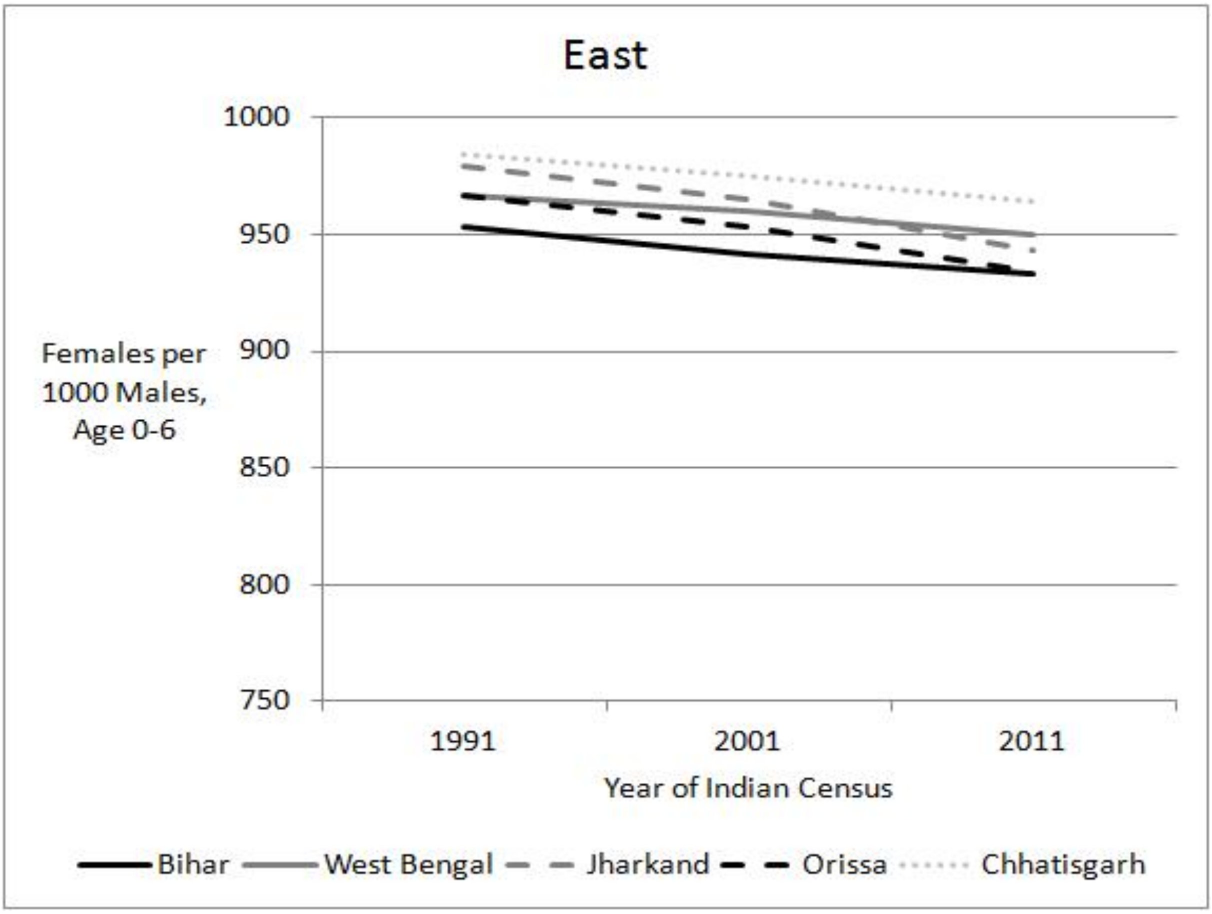

Figure 6: Child Female-Male Sex Ratio: East. Data Source: Indian Census 1991, 2001, and 2011.

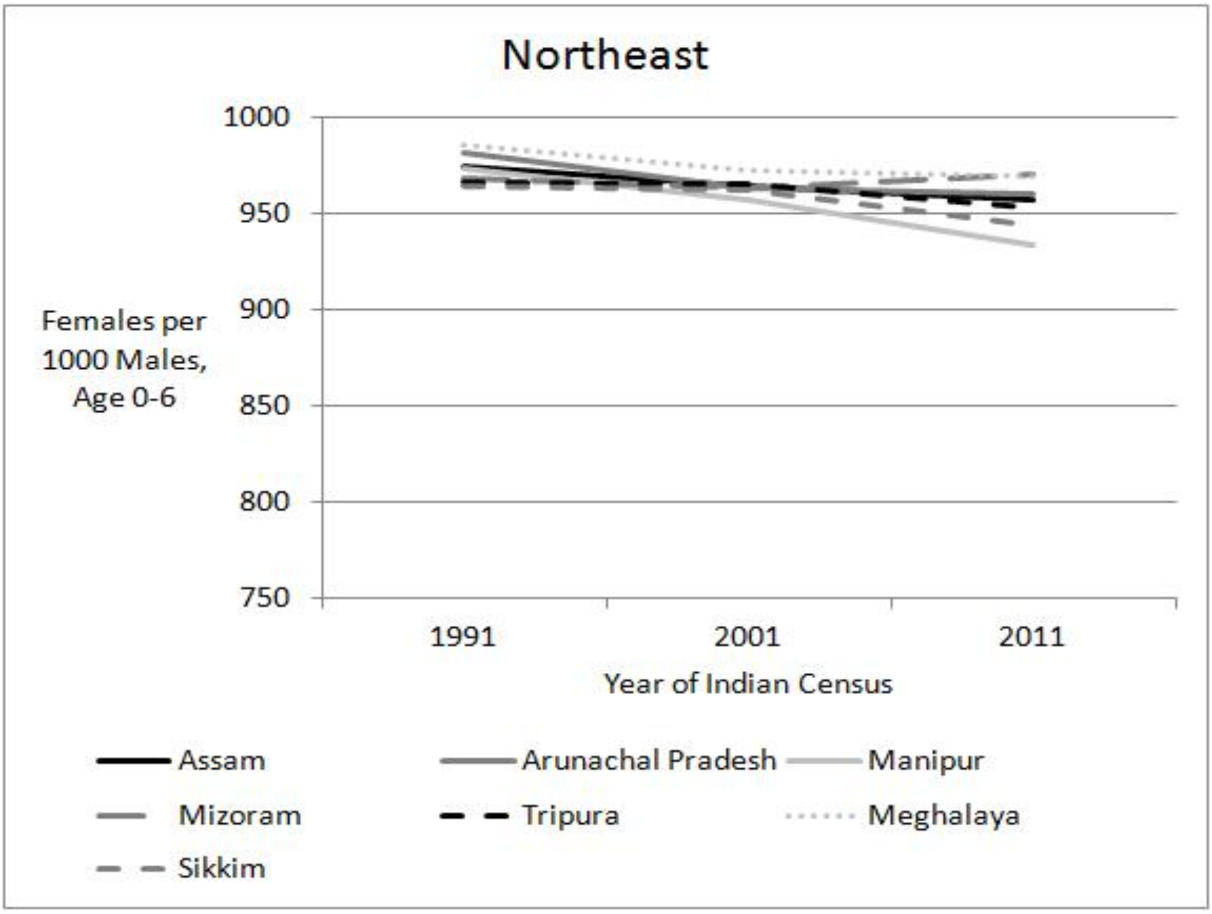

Figure 7: Child Female-Male Sex Ratio: Northeast. Data Source: Indian Census 1991, 2001, and 2011.