Population Sex Imbalance in China before the One Child Policy

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Abstract

Most research on population sex imbalance in China has focused on the One Child Policy era. However, because much of China's fertility decline occurred during the 1970s, we investigate the possibility that sex ratios began rising during this period (as predicted by theory) before the One Child Policy. Analyzing sex ratios between 1960 and 1987 by birth order and sibship sex composition, we find that among couples expected to have the greatest demand for sons (higher parity couples not yet having a boy), sex ratios at birth reached 115-121 boys per 100 girls during the 1970s. Importantly, we also find that these results do not appear to be driven by differential under-reporting of living girls. Given the absence of ultrasound technologies prior to 1979, these results potentially imply the presence of postnatal sex selection in China during the 1970s.

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1. Introduction

China's sex ratio at birth[1] rose dramatically throughout the 1980s (Banister, 2004, Coale and Banister, 1994). A large literature estimates that between 8.5 and 9.2 million females are missing from Chinese cohorts born between 1980 and 2000 – presumably the result of sex selective abortion and childhood neglect (Cai and Lavely, 2003, Ebenstein, 2014, Jiang et al., 2012). Given parental preferences for sons,[2] the One Child Policy (in 1980) and the rapid diffusion of ultrasound technologies capable of detecting fetal sex (during the early 1980s) (Chen et al. 2013) are together generally considered responsible for China's 'missing women' that emerged during the 1980s and later (Banister, 2004, Das Gupta, 2005, Das Gupta and Li, 1999, Ebenstein, 2014, Ebenstein and Leung, 2010, Johansson and Nygren, 1991).[3]

However, demographic and economic theory suggest that as fertility declines in populations preferring sons, sex ratios will rise (Das Gupta and Bhat, 1997, Das Gupta and Li, 1999, Jayachandran, 2015, Jayachandran, 2017, Jayachandran and Kuziemko, 2010) – and strikingly, most of China's fertility decline occurred during the 1970s. In rural areas (accounting for over 80% of the Chinese population in 1970), the total fertility (TFR) fell from 6.4 in 1970 to about 3 by 1979 (and from 3.2 to 1.4 during this period in urban areas; Figure 1) (Banister, 2004, Cai and Lavely, 2003, Coale and Banister, 1994). This decline is among the most rapid documented reductions in fertility in global history.[4] Nonetheless, existing studies of China's fertility decline prior to 1980 are largely descriptive and report

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[1] The sex ratio at birth is defined as the number of boys born per 100 girls.

[2] Scholars have linked China's skewed sex ratio to son preference and patriarchal traditions emphasizing the role of sons in elder care and lineage (Coale and Banister 1994; Ebenstein 2014; Ebenstein and Leung 2010).

[3] Coale and Bannister (1994) find that average sex ratios over 5-year intervals among 3rd and 4th order births rose as high as 109 prior to the One Child Policy (see Table 4 in Coale and Bannister 1994).

[4] Other rapid declines in fertility have occurred in Iran (where the total fertility rate fell from about 6.5 in 1980 to 2.2 during the 1980s and 1990s), and South Korea (where the total fertility rate fell from 6.1 in 1960 to 2.8 during the 1960s and 1970s) (World Bank 2016).

only modest sex imbalance (with unknown quantitative/statistical significance (Banister, 2004, Cai and Lavely, 2003, Coale and Banister, 1994, Das Gupta and Li, 1999, Jiang et al., 2012, Johansson and Nygren, 1991)).

Using historical fertility data (retrospective fertility histories in China's 1988 "Two-per-Thousand" National Sample Survey of Fertility and Contraception), this paper investigates the theoretical prediction that, despite efforts to prevent sex selection, sex ratios at birth began rising as China's total fertility rate plummeted during the 1970s – earlier and to higher levels than previously established. In doing so, it makes several important contributions to the existing literature. First, unlike previous work, it is able to isolate and study the subset of couples among whom the demand for sons is predicted to be the strongest: higher parity couples not yet having a boy (Ebenstein, 2014, Das Gupta, 2005, Arnold and Liu, 1986).[5] Most previous studies use population census data in which births cannot be distinguished by parity and sex composition of older siblings.[6] Second, in estimating sex ratios by single year of age in each year (rather than pooling birth cohorts), it is able to distinguish differential rates of infant death during the first year of life (due either to differential neglect or possible infanticide) from more gradual neglect of girls as they age throughout childhood.[7] Third, it combines graphical and multivariate statistical analyses to test for meaningfully imbalanced sex ratios at birth using a sample restricted to years prior

[5] Although a mother's parity is determined by both live and still births, birth planning policies we study focus on the limiting the number of live births and would have targeted couples based on previous live births. As such, we restrict our analysis to live births, grouping mothers in to parity groups based on the number of previous live births.

[6] Coale and Bannister (1994) show sex ratios by 5 year birth cohort among pooled first and second order births, and pooled third and fourth order births. The authors compare the sex ratios of births by within-sex birth order among babies born in 5 year birth cohorts, showing that girls are more likely to be missing when they have older sisters compared to boys when they have older brothers. However, the authors do not measure the absolute sex ratio among births in each year by birth order and sibship sex composition.

[7] Several studies using census counts show differential mortality rates over time or sex ratios at birth among pooled birth cohorts, neither approach permitting nuanced analysis of the age at which girls are missing from populations Cai and Lavely 2003; Coale and Bannister 1994).

to the introduction of ultrasound technology in each province. This contribution is particularly important for analysis based on fertility histories (in which we know the ages at which girls become 'missing') rather than census counts. Fourth, it pays special attention to potential irregularities in the reporting of living girls, including the adoption of girls, generating new estimates of female under-reporting.

Consistent with theoretical predictions, we find that among third and higher parity births to couples without a surviving son,[8] sex ratios rose as high as 115-121 boys per 100 girls during the 1970s – higher than previously established. Our analysis implies that, although rare in absolute terms (accounting for less than 0.5% of births) and concentrated among a narrow subset of couples, approximately 830,000-955,000 girls are missing from Chinese birth cohorts during the 1970s. Moreover, we find that these missing girls are unlikely to be explained by systematic under-reporting of living children or instances of adoption.

This paper proceeds as follows. Section 2 provides a brief background on sex ratios over time in China and presents a stylized model of fertility decline and sex selection when there is son preference. Section 3 describes our data sources and methodology, and Section 4 presents our primary results. Section 5 then assesses data quality and investigates the possibility of differential under-reporting of female births, and Section 6 concludes.

2. Background and Conceptual Framework

2.1 Sex Selection in China in Recent History

[8] Throughout this study, we characterize the sex composition of older siblings surviving at the time of the relevant birth. Results are robust to the inclusion of all previous births, including children who died earlier (available upon request).

Historical population research provides rich qualitative evidence of high sex ratios during China's Imperial period, extending into the first half of the 20th century (King, 2014, Mungello, 2008, Wolf and Huang, 1980). This work generally attributes the persistence of male-biased sex ratios to a strong preference for sons rooted in patriarchal traditions (Das Gupta and Li, 1999, Ebenstein, 2014, Ebenstein and Leung, 2010, Greenhalgh, 1988, Mungello, 2008). Although there is evidence of advocacy against the practice (Mungello, 2008), families of all social strata used female infanticide and abandonment to control family size and composition (Greenhalgh and Winckler, 2005, Langer, 1973, Lee and Wang, 1999, Mungello, 2008). Some accounts suggest that 10% of female births may have ended this way, with rates as high as 40% among some sub-groups (documented among Imperial families, for example) (Lee and Wang, 1999, Greenhalgh and Winckler, 2005).

The first population censuses conducted in the People's Republic of China (in 1953 and 1964) provide evidence that sex ratios were high during the early 20th century, but then fell around the time of the 1949 communist revolution. The ratio of men to women born during the 1920s and 1930s appears to have ranged between 107.3 and 113.6, peaking during the 1940s at 112.7-117.7 in 1953 (Banister, 1991).[9] Shortly after the communist revolution, China's sex ratio at birth then appears to have fallen to naturally occurring levels below 107 (Banister, 1991).[10] Some research suggests this was due to efforts to promote gender equality and discourage 'feudal' attitudes toward daughters, however son preference persisted as sons continued to

[9] Although it is not possible to distinguish if these high sex ratios emerged at birth or reflect differential mortality throughout childhood and early adulthood, qualitative records suggest that much of this imbalance may have emerged around the time of birth (Song 2012).
[10] The biologically 'natural' sex ratio at birth is generally believed to be 105-107 (Grech 2002; Johannson and Nygren 1991).

ensure lineage continuation and provide greater economic security compared to daughters (Arnold and Liu, 1986, Greenhalgh, 1988).[11]

From 'balanced' levels early in the communist era, existing studies then focus on the rapid resurgence of male-biased sex rations beginning in 1980 under the One Child Policy (and coincident with the diffusion of ultrasound technology across the country). A large body of research suggests that between 8.5 and 9.2 million girls are missing from cohorts born between 1980 and 2000 – generally at very young ages (Cai and Lavely, 2003, Ebenstein, 2014, Jiang et al., 2012). Specifically, in years 1990 and 1995, sex ratios at birth reached estimated levels of 111.8 and 116.6 (Banister, 2004). Unlike earlier years, many studies argue that the diffusion of ultrasound technology (and the ability to detect fetal sex) during this period enabled families to selectively abort girls – effectively making sex selection 'easier' or less costly (Banister, 2004, Cai and Lavely, 2003, Coale and Banister, 1994, Das Gupta and Li, 1999, Ebenstein, 2014, Ebenstein and Leung, 2010, Johansson and Nygren, 1991).[12]

Little previous research reports evidence (or statistically significant evidence) of rising sex ratios during the 1970s – prior to the One Child Policy and diffusion of ultrasound technology. Instead, many past studies are descriptive or focus on establishing 'baseline' population sex ratios to then quantify dramatic increases under the One Child Policy (Banister, 2004, Cai and Lavely, 2003, Das Gupta, 2005, Jiang et al., 2012, Johansson and Nygren, 1991).[13] Nonetheless, modern China's most dramatic fertility decline occurred

[11] Despite the collective organization of agriculture, families remained patriarchal in nature. Property and lineage was passed through the male line and married couples lived with and cared for the husband's parents. Males were also awarded more work points and greater rations compared to female family members and offered greater opportunities for sociopolitical advancement through military or political careers (Ebenstein 2014; Greenhalgh 1988; Greenhalgh and Li 1993).

[12] Media archives and public policy statements discussing female infanticide in the early 1980s suggest that the practice was ongoing in some areas (Greenhalgh and Winckler 2005; White 2000; White 2009).

[13] Coale and Bannister (1994) show sex ratios by 5 year birth cohort among pooled first and second order births, and pooled third and fourth order births. Further, the authors compare the sex ratios of births by within-sex birth order

during this decade. Rural China's total fertility rate (TFR) fell by more than half, from approximately 6.4 in 1970 to about 3 in 1979 (Banister, 2004, Cai and Lavely, 2003, Coale and Banister, 1994). Demographic and economic theory suggest that given preferences for sons, rapid fertility decline (whatever the cause – demand- or supply-driven) should be accompanied by rising sex ratios (Almond et al., 2013, Becker, 1960, Becker, 1991, Das Gupta and Bhat, 1997, Jayachandran, 2015, Jayachandran, 2017, Jayachandran and Kuziemko, 2010, Schultz, 1985). Additionally, this increase in male-biased sex ratios should be concentrated among couples with the greatest demand for sons. Although individual and couple/household preferences are not observed, this group should disproportionately include higher parity couples without a surviving son.

In this next section, we present a stylized conceptual framework for understanding decision-making about sex selection as fertility rates decline.

2.2 A Simple Conceptual Framework for Fertility Decline and Sex Selection

In this section, we formalize the intuition that as family size decreases, male-biased sex ratios increase. Our framework is adapted from Liu, Lin, and Qian (2014), who study the joint effect of legalized abortion and son preference on sex ratios at birth and relative female infant mortality rates in Taiwan. An important distinction is that the cost of sex selection in our model is an *ex-post* cost experienced through neglect; in contrast, most models treat this cost as an *ex-ante* cost (the cost of ultrasound, for example) (Anukriti, 2016, Ebenstein, 2011, Lin et al., 2014).

First, define the household utility function from giving births as:

$$\theta - \lambda \tag{1}$$

among babies born in 5 year birth cohorts, showing that girls are more likely to be missing when they have older sisters compared to boys when they have older brothers. However, the authors do not measure the absolute sex ratio among births in each year by birth order and sibship sex composition.

where θ captures the utility of the child and varies with the child's gender. Specifically, if a son is born, then $\theta = 1 + \delta$; if a girl is born, then $\theta = 1$. $\delta > 0$ therefore captures the strength of son preference. $\lambda > 0$ is a cost parameter for raising children and can broadly be interpreted to include physical, financial, social, and psychological costs. Finally, without loss of generality, we assume households to have a reservation utility of zero from no children.

After a child is born, families can choose to neglect a child, which results in the child's death, with cost $c > 0$. This cost of neglect c broadly reflects the physical, financial, social, and psychological burden of neglect. Households with sufficiently high opportunity cost $\lambda > 1 + \max(\delta - c, \frac{\delta}{2})$ will never have any children. Likewise, households with sufficiently low opportunity cost $\lambda < 1 + \min(c, \frac{\delta}{2})$ will always become pregnant and not neglect. The remaining case includes families with intermediate values of λ, who become pregnant because of the option value of neglecting daughters:

$$1 + \min(c, \frac{\delta}{2}) < \lambda < 1 + \max(\delta - c, \frac{\delta}{2}) \tag{2}$$

Once a daughter is born, households will prefer neglect to raising the daughter when:[14]

$$1 - \lambda < -c \tag{3}$$

Inspection of Equation (2) makes clear that as λ increases, a family's utility from having a daughter decreases – and hence the probability of neglect rises. Figure 2 shows these cases graphically.

In summary, as the cost of children λ increases, more families will choose to have no children, and some families that would otherwise become pregnant without neglect will now

[14] In our framework, a son is never neglected because households with such preferences would never initiate a pregnancy.

become pregnant – but instead neglect their daughters. In the aggregate, the impact on sex ratios is unambiguous: an increase in the cost of children (whatever the cause) leads not only to smaller family sizes, but also increased neglect of daughters and hence rising sex ratios.

3. Data and Methods

3.1 Data

We use China's 1988 National Sample Survey of Fertility and Contraception (also known as the "two-per-thousand" fertility survey), which collected data from 417,518 women in 30 Chinese provinces and municipalities.[15] Conducted by the State Family Planning Commission of China, the survey interviewed a representative sample of ever-married Chinese women ages 15-57 from approximately 14,000 sampling units (neighborhood small group for cities and village small group in rural areas) across the country. This survey was an expanded version of the 1982 National Sample Survey of Fertility and Contraception (the "one-per-thousand" fertility survey) and is generally believed to be accurate and good quality (Coale, 1984, Zhang and Zhao, 2006, Coale and Banister, 1994).[16]

For the purpose of our study, the 1988 "two-per-thousand" fertility survey has several important advantages over its predecessor (the "one-per-thousand" fertility survey) as well as to China's national population censuses. The "one-per-thousand" survey also collected fertility histories, but this did not include information about infant and child deaths, preventing analysis of sex-specific mortality as children aged. China's 1982 and 1990

[15] Provinces and municipalities surveyed include: Anhui, Beijing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Heilongjiang, Hebei, Henan, Hubei, Henan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Ningxia, Qinghai, Shaanxi, Shanghai, Shandong, Shanxi, Sichuan, Tianjin, Xinjiang, Yunnan, Zhejiang.

[16] The data used in our analyses are available upon request.

population censuses have been widely used to study population sex imbalance (Banister, 2004, Cai and Lavely, 2003, Das Gupta and Li, 1999, Ebenstein, 2014, Jiang et al., 2012), but they also lack information about child deaths – and importantly (given our focus), they do not contain sufficient information to estimate sex ratios by birth order, sex composition of previous births, and year. These features may be critical for understanding the early emergence of sex imbalance in the Chinese population (Muhuri and Preston, 1991).

Each sampled woman in the 1988 "two-per-thousand" fertility survey provided detailed information about her complete fertility history, including all pregnancies ending in miscarriage, abortion, stillbirths, and live births. For each live birth, the survey collected the date of birth, sex of the child, whether or not the child was alive at the time of the survey, and if not, the date that the child died. The survey also recorded socio-economic information about each mother, including her own date of birth, ethnicity, province of residence, and urban/rural residency status (*hukou*). Table 1 provides descriptive statistics of mothers having births in selected years during the period of study.

3.2 Methods

Graphical Analysis. We conduct both graphical and multivariate statistical analysis of population sex imbalance by year of birth, birth order, and sex composition of previous births (defined as the presence/absence of a living older male sibling at the time of a given birth – henceforth termed "sibship sex composition"). Our graphical analysis uses each birth, combined with birth records of all children born to the same mother, to determine both birth order and sibship sex composition.[17] We then calculate sex ratios (or the number of males for every 100 females) at birth and at each subsequent year of age up to age 5 by year of birth,

[17] As Footnote 7 describes, our results are insensitive to an alternative definition of sibship sex composition (using indicators for whether or not any preceding birth was a boy, regardless of survival – results available on request).

birth order, and sibship sex composition between 1962 and 1987. Finally, we plot these sex ratios (at birth and at each year of age up to 5) over time.

Given the lack of prenatal sex determination technology prior to the early 1980s (Chen et al., 2013), we interpret sex ratios at birth above the naturally occurring level of 105-106 (Grech et al., 2002, Johansson and Nygren, 1991, Sen, 1990) prior to the 1980s to reflect postnatal selection in favor of males – around the time of birth or in the first year of life, subject to reporting considerations examined in Section 5.

Multivariate Statistical Analysis. We also use ordinary least squares (OLS) regression models to estimate the joint marginal relationship of birth year, birth order, and sibship sex composition with the marginal probability that a given birth is male (relative to 1969). Specifically, we estimate models of the following general form separately for birth order *p* births to mothers *i* in years *y*, grouping third- and higher-order births together:

$$Male_{ijyp} = \alpha + \beta_{ip}^{1} PriorSon_{ip} + \sum_{y} \beta_{y}^{2} BirthYear_{y} + \sum_{y} \beta_{y}^{3} BirthYear_{y} \times PriorSon_{ip} + \sum_{k} \beta_{k}^{4} X_{i}^{k} + \delta_{j} + \varepsilon_{ijyp} \quad (4)$$

where $male_{ijyp}$ is a dichotomous indicator variable for whether or not an order *p* child born to mother *i* living in province *j* in year *y* was male, $BirthYear_y$ is a dichotomous indicator for birth in year *y*, $PriorSon_{ip}$ is a dichotomous indicator for whether or not mother *i* had a previous son surviving to year *y*, and X_i^k is a vector of *k* maternal characteristics (indicators for residence in an urban area and mothers' educational attainment strata, as well as mother's age at marriage). In addition to main effects, we also include all two-way interactions between $BirthYear_y$, and $PriorSon_{ip}$. Equation 4 also includes provincial fixed effects (δ_j), which control for unobserved time-invariant differences across provinces. Supplementary

Tables S1-S2 show that our results are robust to the exclusion of urban and semi-urban populations.

We use linear probability models to allow for consistent fixed effects estimation while avoiding concerns about incidental parameters (Neyman and Scott, 1948). Supplementary Table S3 reports results obtained using probit regressions, yielding comparable findings. We compute Huber-White robust standard errors clustered at the province level, relaxing the assumption that error terms are identical and independently distributed (i.i.d.) across provinces. The resulting estimates of β_y^1 - β_{yp}^3 allow us to calculate the probability of being male in excess of biologically expected levels as a linear combination of year of birth, birth order, sibship sex composition, and all interactions among them. To draw conclusions about what these estimates imply about the prevalence of post-natal sex selection, we restrict our analyses to years before the introduction of ultrasound technology in each province (Chen et al., 2013).[18]

4. Results

4.1 Graphical Analysis

Sex Ratios at Birth. Figure 3 plots sex ratios at birth by year, birth order, and sibship sex composition for each year between 1962 and 1987. At all parities, regardless of previous sons, sex ratios at birth were largely stable throughout the 1960s and early 1970s, oscillating around the natural rate. This is consistent with past analyses suggesting little sex imbalance at birth prior to the 1980s at this level of aggregation (Banister, 2004, Cai and Lavely, 2003, Das Gupta and Li, 1999, King, 2014).

[18] Data on ultrasound availability at the county-year level are from Chen et al. (2013). In our analyses, we adopt a conservative approach, restricting our sample to years before ultrasound technology became available in any county in each province. Including subsequent years increases the magnitude of our estimates.

However, consistent with theoretical predictions, as China's total fertility rate declined during the 1970s, the sex ratio of higher order births depends critically on sibship sex composition.[19] Among mothers with at least one surviving son, this trajectory is also flat, remaining close to the natural rate throughout the 1970s. However, for mothers without sons, the sex ratio at birth rises rapidly throughout the decade – and does so earlier at higher parities. Among third- and higher-order births, the sex ratio among mothers without previous sons rises as high as 120.8 in 1977 (and 115.6 in 1979).[20] This increase in the probability of male births at higher parities among women without living sons then continues throughout the 1980s as fertility declines further, the One Child Policy is introduced, and ultrasound technologies become available.

Sex Ratios at Ages 1-5. Figure 4 repeats the graphical analysis shown in Figure 3 for sex ratios at birth and each single-year age interval up to age 5. Births of each order are shown in separate panels. Relative to the sex ratio at birth within a given subgroup, sex ratios at subsequent ages up to age 5 generally change little. One exception is the modest increase at third- and higher-order births among households without a previous son. Within this subgroup, the sex ratio rises at age 1 by approximately 2-3 additional boys per 100 girls. The stability (and in some cases, increase) in age-specific sex ratios from birth up to age 5 contrasts with biologically higher rates of mortality among boys at all ages (Coale, 1991). Overall, Figure 4 suggests that the majority of China's population sex imbalance during the 1970s occurred around the time of birth.

[19] We conceptualize household fertility decision-making to depend on the sex composition of older surviving children (specifically, the presence of an older surviving son). In practice, all of our results are insensitive to instead using the sex composition of previous births (specifically, the presence of a previous male birth), regardless of survival to the time of a fertility decision. These results are available upon request.

[20] Previous research reports average sex ratios over 5-year intervals at third and fourth parities, regardless of the sex composition of previous births, as high as 109 prior to the One Child Policy (Coale and Bannister 1994).

4.2 Statistical Analysis

The results of our statistical analysis (Table 2) are consistent with Figure 3. We estimate the marginal probability that a child born is male by birth year, birth order, and sibship sex composition, calculating these probabilities using coefficient estimates obtained from Equation (4). Adjusting for observable maternal characteristics as well as provincial and birth year fixed effects, the probability that a first-born child is male does not rise during the 1970s relative to 1969 (the reference year, in which it is 51.5% – approximately the biologically expected rate). After a woman's first child, sibship sex composition then becomes a key determinant of the probability of a male birth. With few exceptions, the probability that a child born to a woman with at least one older living son is statistically indistinguishable from the biologically expected probability throughout the 1970s. However, among women without surviving sons, a third- or higher-order child born after 1973 is 2-5 percentage points more likely to be a male (implying sex ratios at birth of 115.1-129.9).[21]

5. Data Quality and Possible Under-reporting of Living Girls

Because we consider deviations from the naturally occurring sex ratio at birth prior to the introduction of prenatal sex detection technology to reflect postnatal sex selection, a note about potential under-reporting of female births is warranted. Without the technological ability to identify and selectively abort female fetuses, high sex ratios at birth reflect either under-reporting of children born alive that died early in life or under-enumeration of children living at the time of the survey. The interpretation of these unreported female births is central to our paper. We interpret these 'missing girls' to reflect differential rates of infant/child

[21] Estimates are statistically significant for years 1974-1982, with the exception of 1976.

female death, but if the majority of unreported girls were living but simply uncounted, then our interpretation would be incorrect.

Both true sex selection and under-enumeration of living children is well documented in the demography literature for Chinese birth cohorts from the 1980s and 1990s (Cai and Lavely, 2003, Goodkind, 2011, Merli and Raftery, 2000, Zeng, 1996, Zeng et al., 1993, Zhang and Zhao, 2006). However, there is little existing evidence for birth cohorts from the 1970s. On one hand, penalties for violating fertility regulations were less severe prior to the One Child Policy – and hence incentives for hiding unsanctioned births from enumerators were weaker. On the other hand, however, infant deaths may have been unreported in official registries at higher rates in earlier years for simple administrative reasons related to bureaucratic inefficiency (Coale and Banister, 1994, Merli, 1998). Some suggest that on balance, relative to later birth cohorts, the degree of under-enumeration of living children born during the 1970s was substantially less (Coale, 1984, Coale and Banister, 1994, Zeng et al., 1993). To the best of our knowledge, however, no study has empirically evaluated the degree of under-reporting of births from the 1970s in the 1988 "two-per-thousand" survey – including under-reporting by birth order and under-reporting of girls relative to boys.

We use several methods to investigate the extent to which unreported girls lived beyond infancy as unregistered and un-enumerated children, which we present below.

5.1 Adoption and Survey Design

Before applying established demographic methods for assessing under-reporting of living girls, we first briefly consider how the design of the "two-per-thousand survey" (and enumerator instructions) handles adoption – a specific potential form under-reporting.[22] Survey enumerators

[22] If boys adopted into families are reported in our survey's fertility records, or if girls who were given up for adoption are not reported, then the sex ratios that we compute would be inflated.

were instructed to ensure that adopted children ("adopted-in") were not listed in pregnancy histories as "own children" – and also to ensure that children given up for adoption ("adopted-out") were included in these histories. To accomplish this, the survey included cross-validation measures designed to explicitly handle adoptions in this way (SFPC, 1988) .[23] Although we are of course unable to verify how enumerators conducted fieldwork in practice, systematic under-reporting of children adopted-out (along with other types of under-reporting) would be captured by our analyses below in Section 5.2.

5.2 Empirical Assessment of Under-reporting

We then test empirically for systematic under-reporting of living children who could have been adopted-out, or otherwise hidden from enumerators, using three approaches. The first two modify methods used to evaluate the quality of the 1982 "one-per-thousand" national fertility survey, and the third compares the 1988 "two-per-thousand" national fertility survey with the 1982 survey (which is generally considered good quality) (Banister, 2004, Bhrolchain and Dyson, 2007, Coale, 1991, Coale and Banister, 1994).

First, following Coale and Bannister (1994), we investigate the extent to which possibly unreported female births in the 1988 "two-per-thousand" survey 're-appear' as adult women in China's population censuses, focusing on those births most likely to be underreported. We compare sex ratios at birth (number of male births for each 100 female births) for each birth cohort reported in the 1988 fertility survey with sex ratios for the same birth cohorts as reflected in the 1% micro samples of the 1982 and 1990 censuses. From cross-sectional census microsamples, we reconstruct sex ratios at birth by adjusting population counts for age- and sex-

[23] Specifically, before asking questions about each pregnancy, enumerators were instructed to ask how many "own children" were currently living with the respondent, how many were not living with the respondent, how many had been given up for adoption, and how many had died. Summing across these answers, enumerators were then to calculate the number of pregnancies resulting in live birth – including children "adopted-out." If this cross-validation exercise yielded discrepancies, "interviewer should probe for omissions, twins and multiple births, or to see if adoptive children were listed as own children, etc." (SFPC 1988)

specific mortality rates, using a reverse survival method.[24] We find that sex ratios at birth in the 1988 fertility survey are consistent with mortality-adjusted sex ratios observed among the same birth cohorts in both the 1982 and 1990 population censuses (Supplementary Figures S1-S2 and Supplementary Table S4).

To the extent possible, we also investigate the degree to which higher birth order girls (who may have been alive but disproportionately under-reported in fertility histories) are more likely to appear in later population censuses than higher birth order boys. Specifically, we use the same approach described above, stratifying by both birth order sibship sex composition.[25] Due to data requirements, we focus on birth cohorts born between 1975 and 1979 in the 1990 census, adjusting for mortality using birth order-, age-, and sex- specific mortality rates derived from the 1988 "two-per-thousand" survey.[26] We find that girls born at higher parities and with no older brothers – precisely the circumstances under which sex selection is predicted to be strongest – are not more likely to re-appear as adults in future censuses (i.e., we find no evidence of differential under-reporting by birth order and sex composition of previous births) (Supplementary Figure S3 and Supplementary Table S5).

Second, following Coale (1991), we use the 1988 "two-per-thousand" survey to calculate the age-specific rate at which women deliver male and female babies in each year.

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[24] Mortality rates are derived from three sets of life tables. These are: 1) life tables presented in Coale (1984), which interpolate between the 1964 and 1982 censuses; 2) life tables published in Bannister (1991), which use China's Cancer Epidemiology Study of deaths between 1973-1975; and 3) life tables based directly on the 1982 population census (Jiang et al., 1984). For all mortality rate adjustments, we necessarily assume that age- and sex-specific morality rates were stable over the period of study.

[25] Because birth order is not directly reported in the population censuses, we reconstruct birth order and sibship sex composition for the subset of individuals still living with their parents in census years. Specifically, we use the total number of boys and girls ever born to a parent together with the sex and age of each child reported in the household roster, restricting our sample to households in which all children born to a mother still co-resided with her at the time of the census (i.e., children for whom we know birth order and sex composition of older siblings with certainty). To maintain cells of adequate size (by birth year, birth order, and sibship sex composition), we focus on birth cohorts from the second half of the 1970s (1975-1980).

[26] Mortality rates from the 1988 "two-per-thousand" survey are shown to be consistent with life-table sources in Supplementary Figures S1 - S2 and Supplementary Table S4.

We then apply these fertility rates by maternal age and child sex (simultaneously) to age-specific population counts of women reported in population census microsamples (interpolated between the 1964 and 1982 censuses), yielding an estimate of the total number of boys and girls born in each calendar year. We then compare the estimated number of male and female births implied by these calculations to the actual number of individuals in each birth cohort in the 1982 and 1990 censuses to estimate the degree of underreporting for boys and girls by birth cohort in the 1988 fertility survey. We find that although females are slightly more likely to be unreported than males, the difference in rates remains relatively constant over time – and in fact *decreases* during the late 1970s (Supplementary Figure S4). For underreporting of surviving females to confound our main estimates of missing girls, they would need to increase relative to underreporting of males over time.

Third, we investigate the consistency of the 1988 "two-per-thousand" survey with its predecessor, the 1982 "one-per-thousand" survey (which others have shown to be good quality (Coale, 1984)). To do so, we account for demographic changes between survey years by creating a matched sample of women across surveys. Specifically, for every woman in the "one-per-thousand" survey, we identify a woman in the "two-per-thousand" survey with the same characteristics,[27] pooling matched observations from both surveys together. We then regress, separately, (1) the reported number of children (male and female combined), (2) the reported number of male children, and (3) the reported number of female children on a dichotomous indicator variable for which survey the observation was drawn from. The results imply that the number of children (male and female combined) recorded in the 1988 "two-per-thousand" survey

[27] Individuals in each survey are matched using five individual-level characteristics: birth cohort, urban/rural residence, province of residence, educational attainment, and ethnicity. This means that the pooled data set includes an equal number of women from the "one-per-thousand" and "two-per-thousand" surveys, with each observation from the "one-per-thousand" survey matched to an observation in the "two-per-thousand" survey sharing exactly the same characteristics along these five dimensions.

is 0.026 fewer than in the 1982 survey [95% CI: 0.014 - 0.037]. Analogous estimates by sex imply 0.0164 fewer male births [95% CI: 0.010 - 0.023] and 0.009 fewer female births [95% CI: 0.003 - 0.016] in the 1988 survey. Overall, these results suggest a small degree of underreporting in the 1988 two-per-thousand relative to the 1982 survey. However, because underreporting is, to a small extent, *more* severe for male births than for female births, the implication is that our estimates of sex ratios at birth during the 1970s may be biased *downwards*.

6. Discussion

Guided by theory and previous literature, this paper uses fertility history data and a combination of graphical and statistical methods to investigate the possibility of previously undocumented sex imbalance at birth during China's sharp fertility decline throughout the 1970s. Analyzing sex ratios at birth by both birth order and sibship sex composition (simultaneously), we find that among couples predicted to have the greatest demand for sons (third and higher parity births to couples not yet having a boy), sex ratios rose as high as 115-121 boys per 100 girls during the 1970s. Importantly, this finding does not appear to be fully explained by i) under-reporting of female births, ii) the adoption of girls, or iii) pre-natal sex selection via ultrasound.

Infanticide has a long and well-documented history in many cultures, including China during the late Imperial period and during times of political and economic instability in the 20th century (Greenhalgh and Winckler, 2005, King, 2014, Langer, 1973, Mungello, 2008, White, 2009, Wolf and Huang, 1980). This paper provides indirect quantitative measurements of the practice during the 1970s among a small, but quantitatively important, subset of couples.[28]

Overall, our statistical analysis implies that, although rare (accounting for less than 0.5% of births) and concentrated among higher-order births to families without surviving sons, approximately 955,000 girls are missing from Chinese cohorts born during the 1970s.[29] Our graphical analysis using unadjusted data (integrating under the curves shown for sex ratios at birth by birth order and sibship sex composition) yields a comparable estimate of 833,000 missing girls. Importantly, because these male-biased sex ratios at birth emerge prior to the introduction of ultrasound (Chen et al., 2013), they cannot be explained by sex-selective abortion – and instead suggest disproportionately high female mortality rates shortly after birth, either through neglect, or in the extreme, infanticide. More clearly than previous research, our results suggest a serious issue warranting further investigation.

[28] This is consistent with ethnographic reports of incidents of infanticide in the early 1980s (Greenhalgh and Winkler 2005; White 2006).
[29] See online supplemental material for detailed calculations of the estimated number of missing girls during the 1970s.

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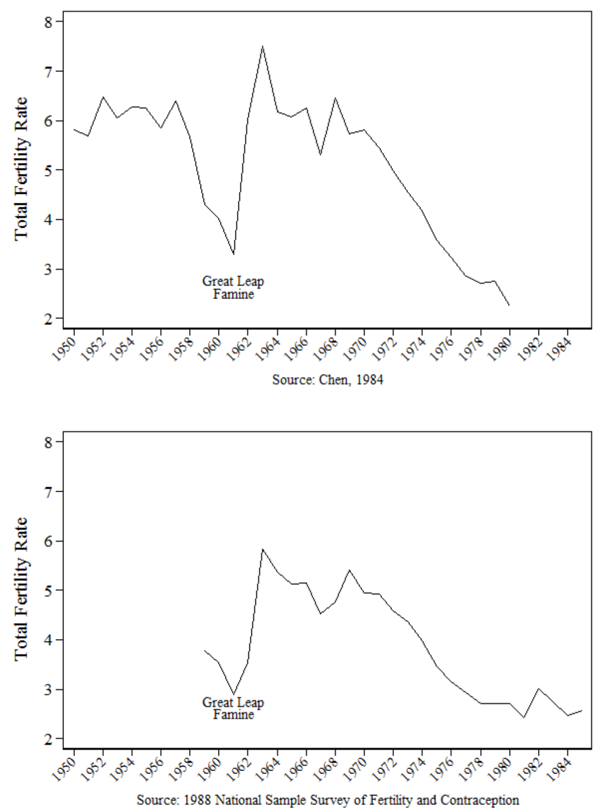
Figure 1: Total Fertility Rate Decline in China 1950-1984



The Total Fertility Rate (TFR) is calculated as the sum of age-specific fertility rates observed in a given calendar year. Panel A is reproduced using TFRs calculated in Chen (1984) from the 1982 National Sample Survey of Fertility and Contraception (the one-per-thousand survey) and Panel B shows highly consistent TFRs calculated using birth records in the 1988 National Sample Survey of Fertility and Contraception (the two-per-thousand survey).

Figure 2: Illustration of Sex Selection by Strength of Son Preference and the Cost of Raising a Child

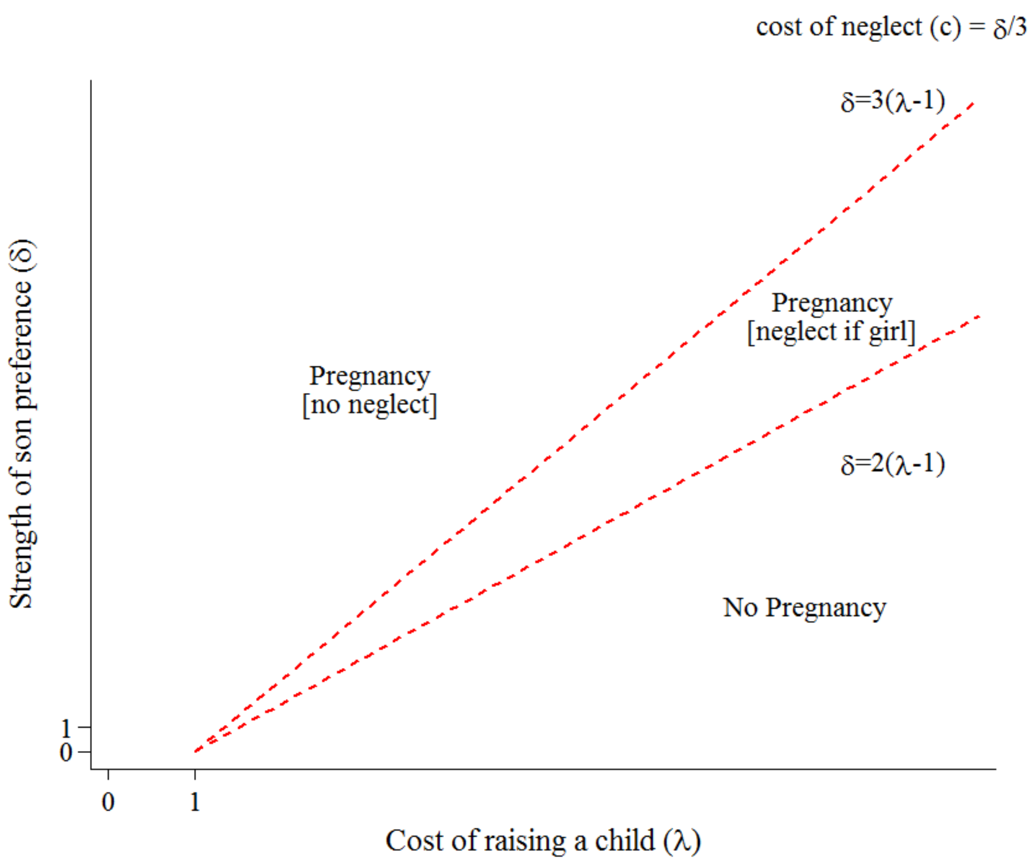


Figure 2 illustrates the conditions under which couples will choose to avoid pregnancy or become pregnant, and the conditions under which couples will neglect daughters following a birth. These outcomes are functions of the cost of raising a child (λ) and the strength of son preference (δ) as described in Section 2.2.

Figure 3: Sex Ratio at Birth by Birth Order and Sibship Sex Composition in China, 1962-1987

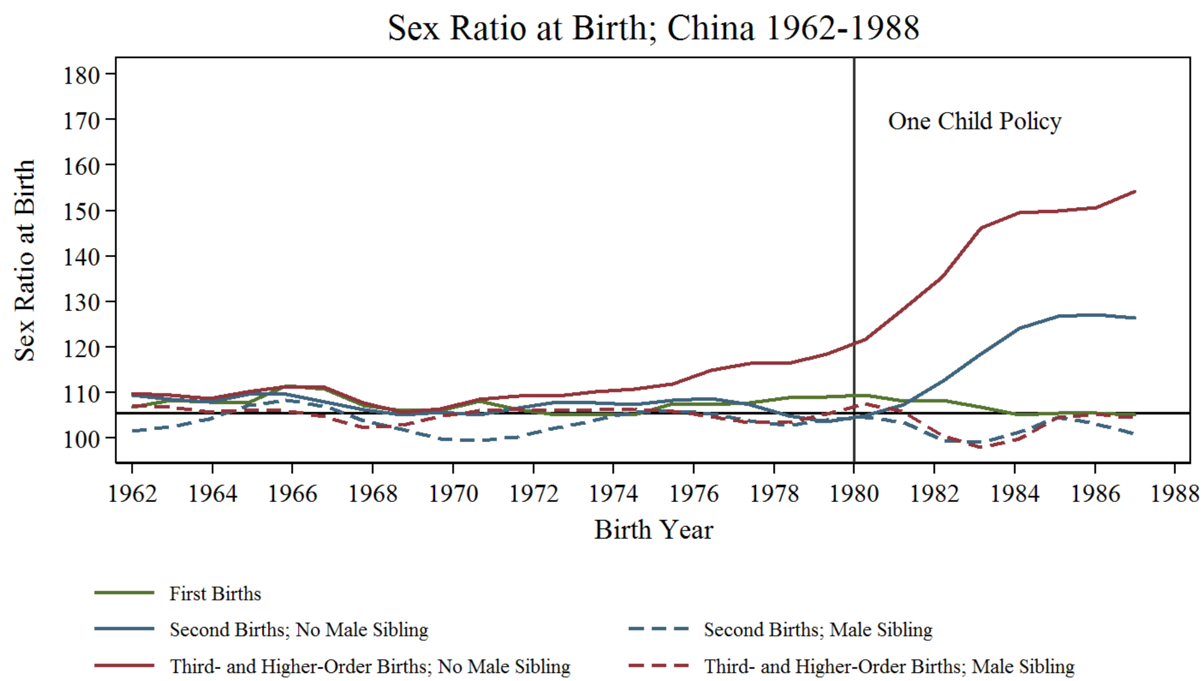


Figure shows reported sex ratio at birth, by birth order and sibship sex composition. Sex ratio is calculated as the number of male births per 100 female births in each parity and sibship sex composition category. Source: 1988 National Sample Survey of Fertility and Contraception.

Figure 4: Sex Ratio at Birth through Age 4 by Birth Order and Sibship Sex Composition in China, 1962-1987

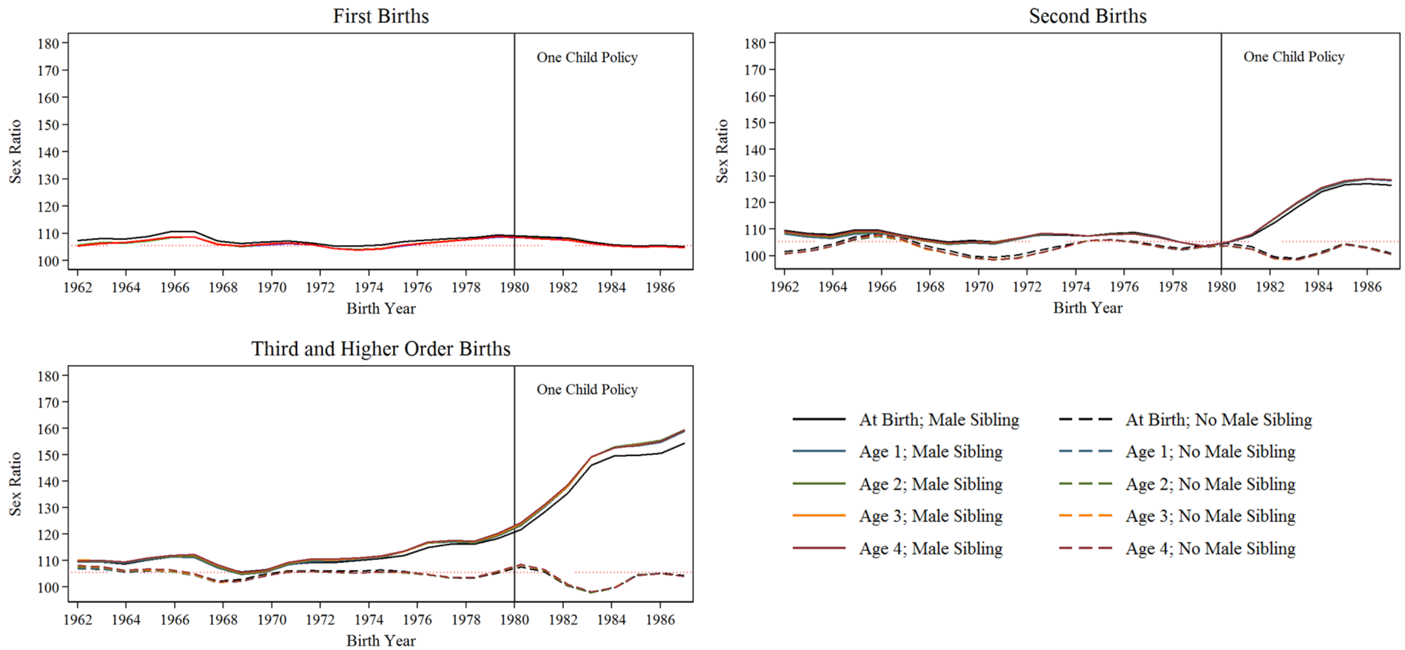


Figure shows reported sex ratio at ages 1-4, by birth order and sibship sex composition. Sex ratio is calculated as the number of male children per 100 female children reaching each relative age in each birth order and sibship sex composition category. Source: 1988 National Sample Survey of Fertility and Contraception.

Table 1:Characteristics of Mothers by Year of Delivery, 1967-1983

	Overall	1967	1970	1973	1976	1979	1982
Illiterate	54.7%	52.3%	46.1%	44.4%	41.3%	38.2%	30.7%
Semi-literate	11.1%	10.8%	10.4%	10.6%	11.1%	10.4%	8.6%
Primary Education	23.9%	25.5%	29.0%	31.1%	31.8%	31.1%	26.2%
Secondary Education or Above	10.3%	11.4%	14.4%	13.9%	15.9%	20.4%	34.5%
Age at Marriage	18.96	19.10	19.46	19.68	20.37	21.33	21.97
Maternal Age	25.96	26.62	27.16	27.35	26.93	26.80	25.95
Rural Household	87.6%	89.0%	88.9%	91.0%	91.8%	91.6%	89.0%

Source: State Family Planning Commission of China, 1988 National Sample Survey of Fertility and Contraception

Table 2: Marginal Probability of a Male Birth, Conditional on Live Birth

	First Birth		Second Birth		Third Birth	
Birth Year	With Surviving Son	Without Surviving Son	With Surviving Son	Without Surviving Son	With Surviving Son	Without Surviving Son
1965		-0.53%	0.39%	1.07%	0.00%	0.27%
1966		2.02% **	1.40%	1.09%	1.24% **	2.53% ***
1967			················ Reference Year ················			
1968		-0.37%	-0.44%	-0.95%	-0.74%	0.61%
1969		-0.58%	-0.74%	0.60%	0.11%	-0.23%
1970		-0.21%	-1.10%	-0.32%	0.51%	0.91%
1971		0.35%	-2.28% **	0.14%	0.25%	1.63%
1972		-1.10%	0.28%	0.53%	1.06% *	1.15%
1973		-0.21%	-1.54%	1.22%	0.05%	1.14%
1974		-1.15%	1.07%	0.13%	1.15% *	2.09% **
1975		-0.44%	-0.10%	0.64%	0.43%	1.41% *
1976		0.30%	0.85%	1.84%	0.81%	1.87%
1977		-0.63%	1.55%	0.74%	0.60%	4.65% ***
1978		0.82%	-1.11%	-0.45%	0.68%	2.49% **
1979		-0.43%	1.20%	-0.52%	1.63% *	3.25% **
1980		0.89%	3.80% **	-0.91%	1.33%	4.85% ***
1981		-0.54%	-0.01%	2.38%	2.34%	4.14% **
1982		-0.39%	4.43% **	3.41%	0.93%	6.32% *
1983		-3.79% **	-4.70% ***	-2.12%	2.39%	5.59% ***

Each cell contains marginal probability that a birth occurring in each year, birth order and sibling sex composition category is male. Marginal probabilities are calculated from coefficients estimated using Ordinary Least Squares linear regressions (estimated separately for births of each order) of an indicator for a male birth on indicators for birth year and the sex composition of older siblings, as well as all two - way interactions between birth year and sibship sex composition. We control for residence in urban area, mother's educational attainment strata, mother's age at marriage, and time-invariant province fixed effects. Huber-White robust standard errors are clustered at the province level. Source: 1988 National Sample Survey of Fertility and Contraception. * $p<0.10$, ** $p<0.05$, *** $p<0.001$.