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Health consequences of sterilizations

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Abstract

In India, as in many developing countries, female sterilization is the main contraceptive method: 37% of women older than 25 are sterilized. However, no economic study assesses the effect of sterilization, providing guidance on efficient reproductive health policies. We analyze the consequences of sterilization for maternal health, considering the endogeneity of the decision. We exploit that Indian households face different infant mortality risks – driven by malaria prevalence – and have a son preference. Sterilization increases when women have a boy first-born, but less so when they live in a malarious area, as they fear losing the boy; this situation provides an instrument. We show that sterilization strongly increases the prevalence of various symptoms in the reproductive sphere while also reducing the risk of anemia, likely from avoiding pregnancy. This paper is the first to assess the effect of a specific contraceptive method with a clear identification strategy.

Keywords: Sterilization; Fertility; Health; Gender; Development.
JEL classification: I15, J13, O1, D1.

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1. Introduction

In November 2014, 12 Indian women died after mass sterilizations in Chhattisgarh, in which the surgeon carried out 80 sterilizations in five hours. In India and in many other developing countries,[1] including Brazil and China, female sterilization is the main contraception available to households that wish to manage their fertility. India spends as much as 85% of its family planning budget on female sterilization,[2] and 37% of women above 25 years old are sterilized.[3] While the demographic side of development has been widely debated among economists, our discipline is almost silent about the best way to control fertility in a poor country. In particular, all contraceptives are not equivalent in terms of the required care, side effects and changes they induce in women's status within the household. This paper analyzes the impact of sterilization on maternal health as a potential hidden cost of fertility control. We do so by using very comprehensive datasets on health and by implementing an identification strategy that relies on exogenous variation in women's willingness to be sterilized.

Our paper is related to several strands of literature. First, from a public health perspective, we provide an assessment of the costs and benefits of becoming sterilized. Wickstrom & Jacobstein (2011) show that the cost of contraception per year of protection for a couple is higher when the couple opts for sterilization rather than non-permanent methods, such as intra-uterine devices.[4] If this is the case, then female sterilization must provide other relative benefits to compensate for the increased cost.

Second, the medical literature has already studied the side effects of contraceptives. While the risks associated with the surgery itself are minor if sanitary conditions are met,[5] sterilization might have several side effects. The main consequences explored by the medical literature are related to the disturbance of ovarian function and to various menstrual and menopausal symptoms, including menstruation abnormality, menstrual pain and dysfunctional uterine bleeding. Desai et al. (2014) focus on a sample of 60 Indian women presenting menstrual irregularities in Gujarat, India, and show that women who have undergone bilateral tubal ligation are more likely to be diagnosed with dysfunctional uterine bleeding. However, they rely on a small sample that is highly selected. Gentile et al. (1998) provide an extensive literature review on the medical effects of sterilization. Their main conclusion is that studies are contradictory and

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[1]For instance, the Dominican Republic, Panama, El Salvador, Guatemala, Colombia, Nepal, Brazil, Nicaragua and China.

[2]80% of this amount was spent on incentives and compensation, rewarding the person who was undergoing the operation, the motivator who brought her to the facility, and the facility staff (Population Foundation of India et al., 2014)

[3]Demographic and Health Survey, 2015–2016.

[4]Female sterilization is estimated to cost $4 per year, which amounts to the cost of the cheapest reliable implants, and is more expensive than intra-uterine devices ($1.75 per year) and vasectomy (i.e., male sterilization, $2.25 per year).

[5]India seems, however, unable to guarantee safe sanitary conditions during surgery. Between 2009 and 2012, the government of India paid compensation for 568 deaths due to sterilizations. Source: *The Guardian*, quoting an answer by the Health Ministry to a parliamentary question in 2012. https://www.theguardian.com/world/2014/nov/12/india-sterilization-deaths-women-forced-camps-relatives. This aspect of the sterilization policy cannot be documented in our paper due to a lack of data.

provide no evidence of post-tubal ligation syndrome. However, existing studies are plagued by two main limitations. First, most are based on very small samples. Second, these studies fail to account for economic characteristics that are often associated with sterilization (such as wealth and education) and do not recognize that sterilization is a choice and therefore might be endogenous to any health outcome.

Besides creating these physiological health effects, sterilization might also harm psychological and emotional health. Sterilization is theoretically reversible, but in practice, this is rarely the case, either for technical reasons or for cost reasons. This irreversibility could generate emotional distress if women regret having the operation. Hillis et al. (1999) followed a sample of 11,000 American women sterilized between 1978 and 1987 and found that 20% of the women sterilized at age 30 or younger expressed regrets within 14 years after sterilization. For a sample of 31,000 Indian women, Singh et al. (2012) observe that regrets tend to increase five years after the sterilization and are higher after the loss of a child. Regrets might be even more likely if sterilization is not the result of a fully informed choice. Balasundaram (2011) reports numerous coercions performed by the health sector on women working in tea plantations in Sri Lanka, while Singh et al. (2012) stress that in India, women from scheduled tribes and Muslim women were more likely to express regrets after sterilization. Poverty might fuel regrets if the operation has been accepted because of the payment involved. Bharadwaj (2015) shows that the decision to undergo sterilization is affected by cash incentives.

Third, sterilization affects other crucial dimensions of a woman's life. The most obvious one is her ability to manage her fertility. While sterilization could be substituted by other types of contraceptives and therefore have only a limited effect on actual fertility, Bharadwaj (2015) has shown that sterilization reduces the number of children: he estimates that getting sterilized leads women to have 0.81 fewer living children on average. A reduced family size might increase income per capita and increase the ability to pay for health care. In addition, Francavilla & Gianelli (2011) show that family planning policies have a significant and positive effect on the employment of women in India. At the same time, informational frictions characterizing rural labor markets might be better mitigated by a greater family size, especially in the completion of tasks for which worker output and effort are difficult to observe. Bharadwaj (2015) shows that larger families have an advantage over small families in this respect and face reduced supervision costs.

Finally, sterilization might also affect the bargaining power of women and, hence, their access to household resources. Again, the direction of the effect is ambiguous. In general, access to family planning is a vector of women's empowerment. Säävälä (1999) shows that young women might adopt early sterilization to enhance their social status with respect to their mothers-in-law. Ebenstein et al. (2013) also conclude that family planning improved women's bargaining power in China. To the contrary, Anukriti & Persson (2014) highlight how female sterilization increases spousal violence. Given these various elements, the effect of sterilization on maternal health is clearly ambiguous and needs to be empirically estimated.

Since sterilization has been so scarcely documented in the economic literature, we begin by providing a comprehensive description of the history of family planning policies in India, of the current use of contraceptives, of the spatial heterogeneity of sterilization and of the self-assessed side effects of this surgery. Second, we implement an instrumentation to account for the likely endogeneity of the choice to become sterilized. Namely, we exploit both the preference for sons and the fact that sterilization is postponed by women when they fear losing a child. In India, malaria is historically one of the key causes of infant mortality. Having a male first-born and malaria prevalence are two determinants of the decision to become sterilized. While neither of these two variables satisfies the conditions to be valid instruments, the interaction between the two, combined with village fixed effects, satisfy the exclusion restriction we need to identify the effect of sterilization on maternal health. We offer a theoretical model that justifies the choice of the instrument. We find that the prevalence of various symptoms in the reproductive sphere and pain during sexual intercourse increase by 50% to more than 100% as a consequence of sterilization, but that sterilization also reduces the risk of anemia, likely from a decrease in the number of pregnancies. We also show that the adverse effects of sterilization take time to materialize (three years) and then remain steady. Our study has a strong external validity since we use two samples containing approximately 400,000 observations each and we show that women with various characteristics are affected by the instrument. Placebo tests show that there is no effect of sterilization, once instrumented, on women's health prior to the sterilization.

The paper is structured as follows. Section 2 presents the data, and female sterilization in India is described in Section 3. Section 4 describes the identification strategy, and Section 5 provides the results and several robustness and placebo tests.

2. Data

2.1. DLHS

The District Level Household Survey (DLHS 2) collected in 2002–2004 from 640,000 women has several strengths that make it highly suitable for our study.[6] First, the survey is representative of the national population and the sampling rate is high: we observe on average 850 households per district. Second, for one woman in the household, the data include very detailed information on her pregnancy history and her contraception and fertility choices, including whether she has undergone sterilization and when. Third, an extensive health module records detailed information on symptoms in the reproductive sphere. This dataset thus offers the opportunity to explore both short-term and long-term effects of sterilization.

2.2. DHS

We complement the previous dataset with the Demographic and Health Surveys (DHS, called the "National Family and Health Surveys" in India) that were collected in 1998–1999

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[6]We do not use a more recent DLHS for the following reason: in DLHS 3, the full birth history of women is not collected, which is necessary for our identification strategy; in DLHS 4, only some states were surveyed.

(DHS 2) and in 2015–2016 (DHS 4). These surveys are particularly interesting from the health perspective since they collect anthropometric and biological measurements of women, including height, weight and hemoglobin level.[7] We know that health is a multidimensional concept, and this information, coupled with the DLHS recording of symptoms, allows us to offer a comprehensive view of women's health. The hemoglobin measurement is of particular interest since most Indian women are anemic. Like the DLHS, the DHS is representative of the national population. While the sampling rate of DHS 2 is lower (it has enumerated 90,000 women), it is very high in DHS 4 (700,000 women surveyed across 640 districts). The DHS also records the past history of pregnancies and sterilization status of women. We describe later the data we use for identification.

3. Female sterilization in India

3.1. History of Indian family planning

Family planning policies have a long history in India. In 1952 began what would become the largest government sponsored family planning program in the world. Cash incentives were introduced in 1967, as the program gradually expanded. Sterilization policies were promoted by Indira Gandhi in 1976 in order to reduce demographic growth and facilitate economic takeover. Forced sterilization campaigns were implemented in 1975–1977, mainly targeting males. The coercion and the violence involved in this process left profound scars.

In the 1980s, the family planning program continued on a voluntary basis and shifted towards targeting women. In 1981, a centrally sponsored scheme was launched. Individuals who became sterilized would receive cash incentives, while the medical facilities where the operation was performed would receive additional funds. Typically, the compensation package provided cash to the individual accepting sterilization (the "acceptor"), to the various actors involved in the operation (the surgeon, anesthetist, staff nurse, and technicians), and later to the person who convinced him or her to become sterilized (the "motivator").

The details of this breakdown were left to the states, provided that some minimum amounts would be paid to the acceptors and used by the medical facilities (for instance, for tubectomy, acceptors should receive at least Rs 150, and a minimum of Rs 60 had to cover drugs and dressing in the facility). IUD insertions were included in the package, involving a transfer of Rs 20 to the medical facility in order to cover actual costs, but nothing was given to the acceptor.

The package's composition has differed by states and, later on, by population category. In 2001, an "Empowered Action Group" (EAG) was set up in order to develop programs in eight states,[8] which not only ranged among the poorest states in India but also displayed the highest population growth in the country. In these states, compensation packages for female sterilization

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[7]In the main analysis, we do not use the DHS 1 because there are no health measurements for women, and we do not use DHS 3 because we cannot identify districts, which is necessary for our instrumentation. However, they are used in some instances in the paper to provide complementary information.

[8]The eight EAG states are Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Orissa, Rajasthan, Uttar Pradesh and Uttaranchal (named Uttarakhand since 2007).

were increased. Some states also created special funds in order to pay ex gratia to the acceptor of sterilization or her relatives in case of death, incapacitation, or treatment of post-operative complications.[9] In the early 2000s, the number of claims for compensation after the failure of sterilization or complications faced by government doctors contributed to various measures aiming at improving the quality and the enforcement of sterilization procedures (Ministry of Health and Family Welfare, 2005). It also led to the creation of a Family Planning Insurance Scheme in 2005, providing indemnity insurance covering doctors and health facilities in the case of failure or complications due to the operation.

Additional increases followed in 2006, 2007 and 2014. In 18 states (the "High-Focus States"[10]), the increase was unconditional, regardless of acceptor characteristics. In the other states, the increase targeted only individuals below the poverty line or belonging to a scheduled caste or a scheduled tribe. In 2014, the compensation package was further increased in the 11 states with the highest fertility rates.[11]

Today, in theory, the cash incentive associated with a sterilization varies from Rs 250 (for individuals above the poverty line becoming sterilized in a public facility in a non-High-Focus State) to Rs 1400 (for individuals becoming sterilized in a public facility in one of the 11 previously mentioned states).[12] The compensation ranges from PPP$15 to PPP$82. 92% of women sterilized in 2014-2015 reported having received compensation; the reported amounts are on average slightly above Rs 800. This amount is called a "compensation" because it is supposed to compensate women for the time lost during their post-sterilization recovery. Despite the fact that the Indian government attempts to adopt a more diverse approach to family planning,[13] the main trend has not yet been reversed.

Since 2006, community health workers have not earned a fixed salary for their activity but are paid only according to their results, which includes convincing women to become sterilized. In total, a sterilization performed in a High-Focus State costs at least Rs 2000 (taking into account all the payments that are made by the state but not spending associated with maintaining the health care system more generally), which is roughly PPP$118. If the state offers contraception for 20 years, it costs roughly PPP$5.8 per year. Despite the fact that sterilization payments have varied over time and by location, it is worth mentioning immediately that we will not exploit this variation for the two following reasons. Even though there was variation, it was actually common for a large number of states to be grouped into two main categories. As a

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[9]Rs 50 000 in case of death, Rs 30 000 in case of incapacitation, Rs 20 000 in case of complications.

[10]The High-Focus States are Bihar, Uttar Pradesh, Madhya Pradesh, Rajasthan, Jharkhand, Chhattisgarh, Uttarakhand, Orissa, Jammu & Kashmir, Himachal Pradesh, Assam, Arunachal Pradesh, Manipur, Mizoram, Meghalaya, Nagaland, Tripura and Sikkim.

[11]Bihar, Uttar Pradesh, Madhya Pradesh, Rajasthan, Jharkhand, Chhattisgarh, Uttarakhand, Orissa, Assam, Haryana and Gujarat.

[12]Sterilizations performed within seven days after delivery involve an extra payment of Rs 600. Payments obtained in accredited private facilities depend on the facility.

[13]The new scheme also includes the promotion of IUDs, and the compensation given for vasectomy increased. Source: http://www.thehindu.com/sci-tech/health/policy-and-issues/gendered-approach-to-sterilisation/article6742284.ece.

result, the variation is very limited. The second important issue is that such changes in policy occurred together with other health policy reforms.[14]

3.2. Use of contraceptives

As a result of this major policy focus on female sterilization, this contraceptive method is by far the most widely used in the country: in 2015-2016, nearly 24% of the surveyed women in the DHS were sterilized. While slightly less than half of the surveyed women report that their couple uses a contraception method, sterilization is used by 62% of them. Table 1 presents the different contraceptive methods used by couples: condoms are used by 4% of the respondents, pills and IUD are used by only 4.5% of the respondents, while traditional methods (mostly periodic abstinence and withdrawal) are used by roughly 6% of the respondents. Male sterilization was chosen by less than 1% of the couples.

Table 1: Contraception method currently used by women

| Any method of | Percentage of women | | |
contraception used?	All women	Among women having given birth	Among women who have not given birth
Female sterilization	23.67	34.71	0.09
Male sterilization	0.26	0.37	0.01
Condom	4.22	5.75	0.95
Oral pills	3.09	4.44	0.20
IUD/copper-T	1.37	2.00	0.02
Rythm/periodic abstinence	2.55	3.63	0.25
Withdrawal	1.94	2.72	0.27
Other modern method	0.17	0.25	0.01
Other traditional method	0.07	0.10	0.00
No method - nonpregnant	58.03	41.88	92.53
No method - pregnant	4.63	4.15	5.67
Total	100	100	100
Observations	699 686	476 619	223 067

Sample: surveyed women in DHS 4 (2015-2016). The question bears on the contraception method used at the time of the survey.

The sample of interest is women who have already given birth, as few women will undergo sterilization before giving birth. As Table 1 shows, women who have not given birth are most likely to not use any contraception method. In what follows, percentages will be computed for the population of women who have already given birth.

3.3. Spatial heterogeneity, age at sterilization and place where sterilization is performed

There is a large spatial heterogeneity regarding the use of the various contraceptive methods, the age at sterilization and the facility where sterilization was made available to women.

Figure 1a reports the percentage of sterilized women in the DHS 4 by district. While in some states in the north-east of India (like Uttar Pradesh), the district average is below 20%,

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[14]For instance, each time cash incentives associated with female sterilization were increased, cash incentives for IUDs and male sterilization were increased as well.

in numerous districts located in the center and in the south-east, more than 60% of women are sterilized. In several districts of Andhra Pradesh, the percentage rises above 70%.

Figure 1: Characteristics of sterilization by district

(a) Percentage of sterilized women

(b) Average age at sterilization
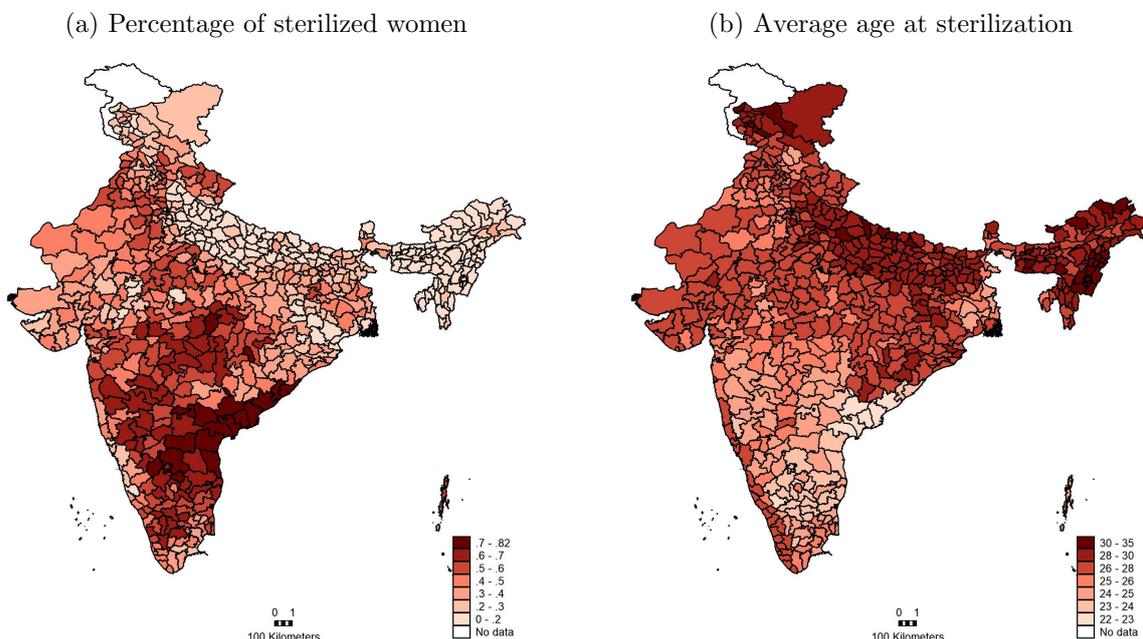
Source: DHS 4, women who have given birth.

Source: DHS 4, sterilized women.

In DHS 4, women report the age at which they were sterilized. The average age at sterilization is 27 years old; 10% of the sterilized women are sterilized under or at the age of 21, and 50% are sterilized at younger than 26 years old. We compute the probability of being sterilized by age and for three different cohorts (Figure 2a). Sterilization take-up increases steadily between 20 and 35 years old and then flattens between 35 and 40 years old. More recent cohorts are willing to be sterilized sooner than the older cohorts but end at similar levels of sterilization at 40 years old. As a consequence, the total fertility rate is lower for the most recent cohort (2.8 living children at 40 y.o., see Figure 2b). Figure 1b maps the average age at which women have been sterilized by district. Women living in the southern states also become sterilized at an earlier age.

The DLHS 2 survey provides information on the place where the sterilization was performed. While 53% of women went to a public hospital, around 19% went to a public health center; 12.5% of women were sterilized in a camp or in a mobile clinic, and 13.8% went to the private sector (see Table A1 in the Appendix). This distribution might have implications both for the quality of the health care provided and the likelihood for women to receive any follow-up care. Only a minority (28%) of women sterilized in a public hospital report any care (Table A1, column (2)). Women sterilized in camps appear more likely to have received follow-up but they are also more likely to report health problems due to the sterilization (Table A1, column (3)). Again, there is a considerable spatial heterogeneity regarding the facility where women were sterilized. Figures A1a and A1b show the proportion of women going to a public hospital

Figure 2: Sterilization and number of children, by age and cohorts

(a) Probability to be sterilized, by age   (b) Number of children, by age

○ Cohorts 1965-69   × Cohorts 1970-74
+ Cohorts 1975-79
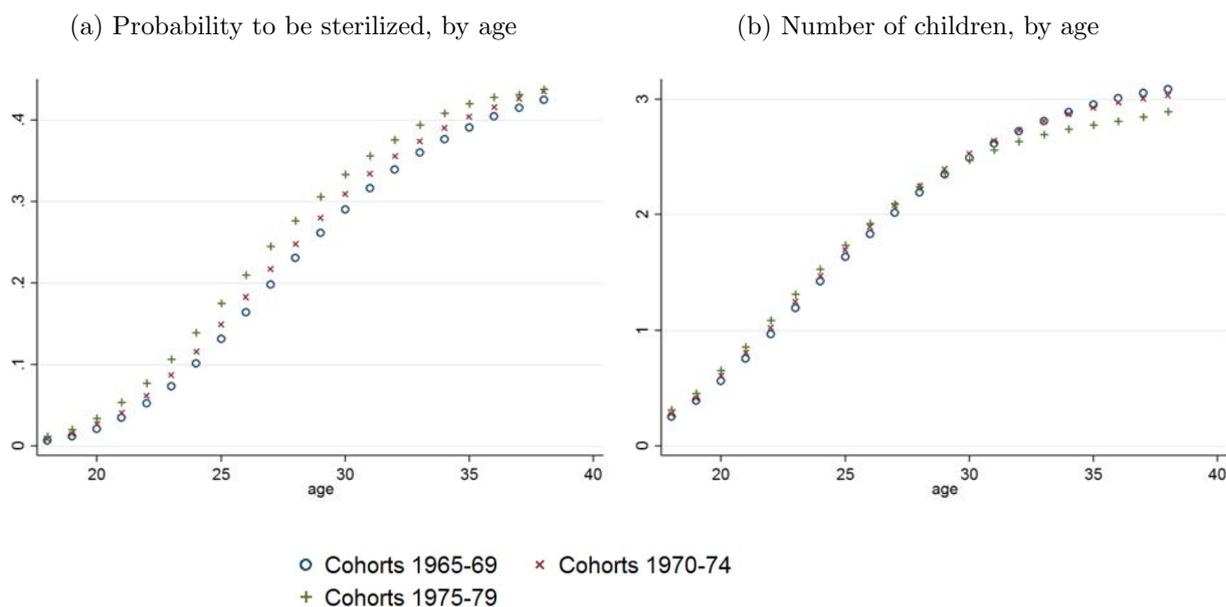
Source: DHS 4, all sampled women.

or to a camp, respectively. In the northern and the southern tips of India, the vast majority of women (more than 75%) go to public hospitals. In central states, women are more likely to be sterilized in camps than are women in the rest of the country.

3.4. Individual determinants of sterilization

In order to assess the individual determinants of sterilization, we predict the probability of being sterilized for various socio-economic characteristics, controlling for village fixed effects. Table 2 indicates that Hindu women are more likely to be sterilized. Interestingly, women with low education levels are more sterilized but, conditional on education, wealthier women are more likely to be sterilized.[15] The results are consistent in the various samples and descriptive statistics on the samples are provided in Table A2.

3.5. Self-assessed side effects

In DLHS 2, women report the problems they have experienced with contraception. Twelve percent of women using contraceptives report experiencing problems due to their contraception. Table A3 in the Appendix displays, by contraceptive type, the percentage of women reporting side effects. This percentage varies across contraception methods and is the highest for sterilization (17%). These women are further asked about the nature of the health problems encountered, and below, we check that our results are consistent with the self-declared side effects.

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[15]We build a wealth index using housing characteristics and ownership of durable goods.

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Table 2: Probability of being sterilized

	(1) DLHS - 2	(2) DHS - 2	(3) DHS - 4
Current age of respondent	0.000	0.012***	0.014***
	(0.00)	(0.000)	(0.000)
Education	-0.006***	-0.010***	-0.011***
	(0.00)	(0.001)	(0.000)
Sikh	-0.036***	-0.050**	-0.043***
	(0.01)	(0.022)	(0.012)
Buddhist	-0.023**	0.035	0.008
	(0.01)	(0.024)	(0.006)
Christian	-0.000	-0.056***	-0.021**
	(0.01)	(0.014)	(0.008)
Muslim	-0.133***	-0.141***	-0.122***
	(0.00)	(0.008)	(0.006)
Other or no religion	-0.014**	-0.002	-0.033***
	(0.01)	(0.017)	(0.010)
Scheduled caste	-0.020***	-0.024***	-0.000
	(0.00)	(0.006)	(0.004)
Scheduled tribe	-0.046***	-0.074***	-0.021***
	(0.00)	(0.011)	(0.005)
Wealth	0.005***	0.012***	0.004***
	(0.00)	(0.002)	(0.001)
Observations	440 626	80183	457386
Village FE	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The regression is a linear probability model on the sterilization status. Village fixed effects are included in all the columns. The standard errors are clustered at the village level.

3.6. Alternatives to sterilization

Before exploring the health issues affecting sterilized women, we describe the comparison group. For the sample of interest, namely, the sample of women who have already given birth, Table A4 in the Appendix reports what the couples do when the woman is not sterilized. Women who are not sterilized did not, as a majority, use any other contraceptive method at the time of the survey.

When we estimate the effect of sterilization, we will therefore compare women who became sterilized to women who did not and use this "bundle" of alternatives (no contraception, condoms, traditional methods and some pills or IUDs). Therefore, the effect of sterilization is estimated by comparing sterilized women with women who mostly do not use any other modern contraceptives. India provides us with an environment in which we can identify the effect of one type of contraceptives since almost no other contraceptives are used.[16]

4. Empirical strategy

4.1. Model

We now discuss the identification of the effect of sterilization. Becoming sterilized is a decision very often jointly made by the woman, her husband, and even her mother-in-law. This decision reflects preferences over family size, gender composition, perceived risk of child mortality, willingness to invest in different types of human capital, availability of different contraceptives, availability of health care more generally, and the potential pressure exerted by the health care system. The previous section has described the characteristics of adopters, but no clear-cut picture emerges from the description. The fact that wealthier women and less educated women simultaneously tend to adopt sterilization suggests that the selection cannot be categorized as positive or negative. Additionally, women likely take into account their own health before deciding whether they want to undergo the surgery. Women who have serious health issues may be more prone to become sterilized if they fear that another pregnancy could be fatal to them; or, to the contrary, only healthy women might decide to take up sterilization if the surgery is perceived as detrimental to their health. As a result, it is difficult to predict the sign of the bias when neglecting the omitted variable bias.

We take into account the endogeneity of the sterilization choice by controlling for observed characteristics of the household and the woman, controlling for unobserved characteristics of the village (by running village fixed effects regressions) and by implementing an instrumentation strategy that we describe below. In order to control for village fixed effects, we run the following estimation:

$$Y_{iv} = \alpha_0 + \theta Ster_{iv} + \mathbf{X}_{iv}\Lambda_0 + \delta_{0v} + \epsilon_{iv} \tag{1}$$

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[16]In addition, for many existing studies taking place in developed countries, knowing women's past use of contraceptives is important, as it might influence menstrual symptoms as well (see Gentile et al., 1998). In our case, this distinction is of minor importance, as other contraceptives are barely used in India. Even if all women using IUDs or oral pills at one point in time become sterilized, they will constitute a small minority of all sterilized women.

Y_{iv} is an outcome variable related to the health of woman i living in village v, $Ster_{iv}$ is a dummy equal to 1 if the woman has been sterilized, $\mathbf{X}_{iv}$ is a vector of household characteristics and δ_{0v} are village fixed effects. Controls include age, education, religion, caste and wealth. We now turn to the presentation of the identification strategy.

4.2. Preference for boys

The preference for boys in India is widespread and does not need to be demonstrated anymore. As shown by Bhalotra & Cochrane (2010), households target a given number of boys.[17] As a result, the desired family size changes when the sex composition of the first-born becomes known to the parents. Parents who have a boy first end up with fewer children than those who have a girl first. We focus on the first-born for two reasons. First, all households, even more modern households, wish to have at least one child. We can thus consider that having a first child is an event that is beyond the parents' choice. Second, and more importantly, Indian households are also known for selecting children on their gender basis. However, Bhalotra & Cochrane (2010) show that the sex ratio of the first-born at birth is within the "natural" range: it seems that parents do not sex-select for the first pregnancy. Figure 3 plots the sex ratio for first and second births from 1980 to 2015. It illustrates that while the sex ratio of the first born remains in the natural range (Figure 3a), the introduction of ultrasound sex detection devices has deteriorated markedly the sex ratio for second births when the first child is a girl (Figure 3b).

Figure 3: Sex ratio at birth

(a) Sex ratio for first births   (b) Sex ratio for second births
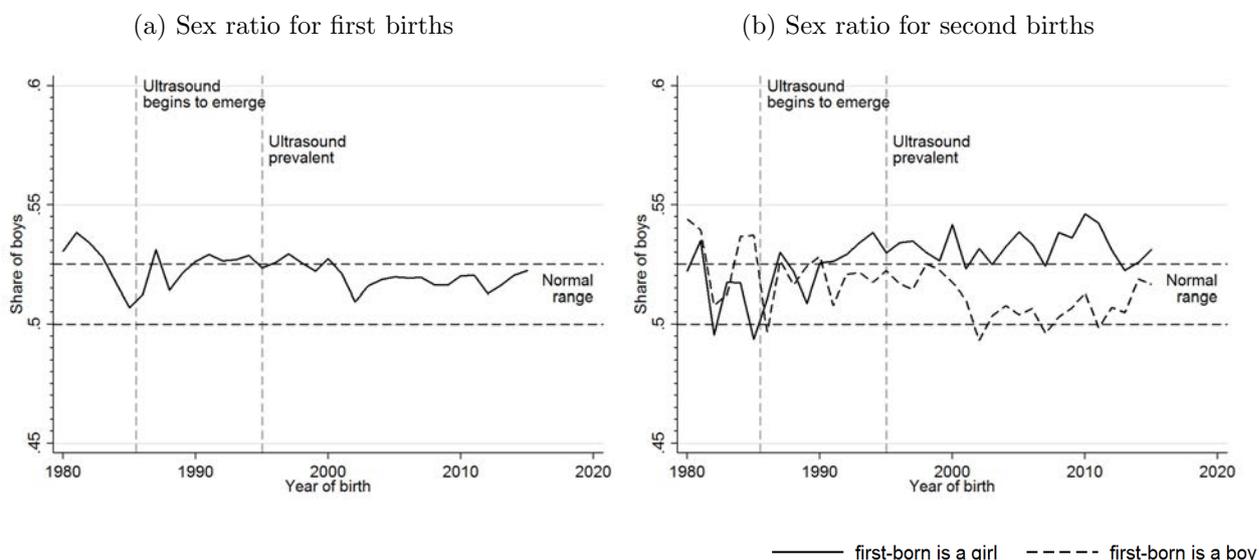
Data: DHS 2, DHS 3 and DHS 4. First and second births recorded for women under 40 years old.

The gender of the first-born is therefore an "external" event[18] that is not driven by parents'

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[17]Bhalotra & Cochrane (2010) find that the average household wishes to have two boys.

[18]The terminology employed here refers to that offered by Deaton (2010).

preferences. This context, however, does not guarantee the exogeneity of gender with regard to maternal health. If women are better treated when they give birth to a son, then the gender of the first-born affects both sterilization decisions and the woman's health. In particular, Milazzo (2018) shows that women who have a male first-born are less likely to suffer from anemia and less likely to die at young ages than women who have a female first-born.[19]

4.3. Infant mortality

We also exploit the fact that women facing a higher risk of infant mortality should be more reluctant to adopt a permanent contraceptive, as documented in anthropological works (Patel, 1994). Indeed, women are more likely to regret sterilization if they have lost a child: in DHS 4, 7.2% of sterilized women regret the operation. Fifteen percent of sterilized women lose a child after they were sterilized. The loss of a child after the operation significantly increases the likelihood of regretting the operation by 7.8 percentage points and thus has a strong impact on the likelihood of expressing regrets.[20]

However, infant mortality is unlikely to satisfy exclusion restrictions: areas with higher infant mortality are presumably also those where health care is of poorer quality and women could suffer from such poor quality. We will therefore focus on malaria prevalence, which is a specific cause of infant mortality. Pathania (2014) and Chang et al. (2014) have both shown the adverse impact of malaria on child mortality (in Kenya and Taiwan, respectively). If malaria prevalence is affected by health policies implemented to fight against it (provision of bednets, parasite diagnostic kits and improved antimalarial medicines, interventions reducing reservoirs/waterholes and improving vector control, etc.), it also has a strong exogenous component: climate. Indeed, the size of the mosquito population and the ability of the malarial parasite to develop depend on temperature, rainfall and land-surface heterogeneity (see subsection Appendix A.2 of the Appendix for details). The malaria incidence predicted by the climate–disease model of Lauderdale et al. (2014) captures only the exogenous component of malaria prevalence. This type of model has been previously used by Oster (2012) to predict life expectancy on Africa. However, because malaria, even based on climate factors, should affect population health, we do not assume its exclusion from the main regression.

The Lauderdale et al. (2014) model uses the most reliable existing sources on rainfall and temperature.[21] Figure 4a displays the annual incidence of malaria as simulated by Lauderdale et al. (2014) for the period 1998–2010. Figure 4b shows the malaria endemicity as measured

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[19]In the paper, she links anemia and death events to reduced birth spacing and an increased number of pregnancies. They could also be associated with sterilization decisions.

[20]This effect is obtained from a regression of expressing regrets on under-five child loss, woman's education, caste/tribe, religion, wealth and village fixed effects. The loss of a child before the operation has no effect on the likelihood of regretting the operation.

[21]Rainfalls are provided by the Tropical Rainfall Measuring Mission (TRMM), which has a fine grid of $0.25° \times 0.25°$, while temperatures are obtained from the Interim ECMWF Reanalysis (ERAI). TRMM has been shown to be a very reliable measure of rainfalls for tropical regions and in particular for India; it combines various satellite measures with local ground rain-gauges. Where rain-gauges are missing, the interpolation relies on a calibrated measure of the relation between cloud temperature and *in situ* observed rain (and not on a linear interpolation, which is often a flaw of gridded data). ERAI has a spatial resolution of $1.5° \times 1.5°$.

by the National Vector Borne Disease Control Programme for the year 2010 and mapped by Das et al. (2012). We observe similarities between the two maps, which is expected, but we also find that in some areas (the southern states, for instance) they differ markedly. This likely comes from the fact that these states are wealthier and therefore more equipped for fighting the disease.

Figure 4: Climate-driven predicted malaria and actual malaria

(a) Climate-driven malaria, as predicted by the Lauderdale et al. model

(b) Actual malaria, in Das et al. (2012)
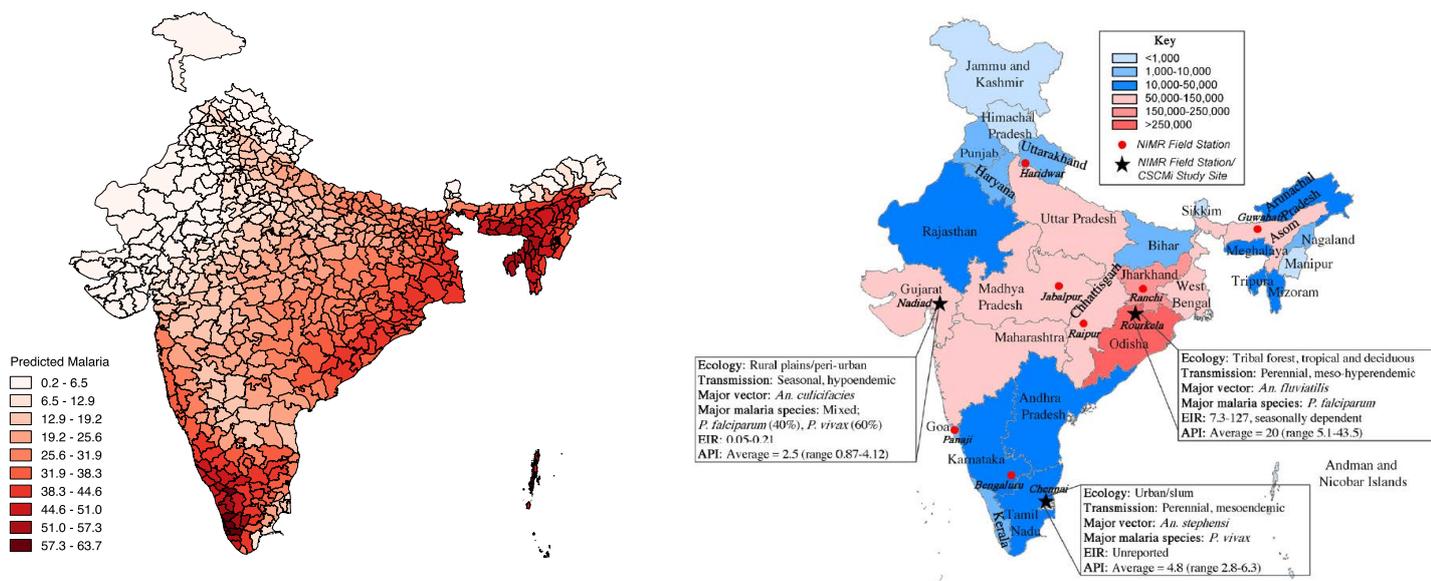
As mentioned, we use the modeled malaria based on climate for the 1998–2010 period. We do not use temporal variation in rainfall and temperature because we consider that women, when making their sterilization decisions, appreciate the risk of infant mortality through interactions in their network (close family and neighbors). Relatively rare events such as child death might be transmitted over years and maybe even generations. We return to this question below.

Last, the information obtained from the model is provided in grids, but we simply aggregate the information at the district level to be matched with our datasets. We can also match the information at a lower administrative level (called block/taluk/tehsil), but this does not change the results (neither in terms of point estimates nor in precision).

4.4. Preference for boys and infant mortality

Because households wish to ensure a male offspring, they not only postpone sterilization when the first-born child is a girl, they should also postpone sterilization when they have a male first-born but face a high risk of infant mortality. Put differently, for a given risk of infant mortality, households should postpone sterilization more if their first-born is a boy. Appendix Appendix A.3 provides a theoretical model in which parents make the sterilization decision based on their target number of boys and girls, on the health costs for the mother associated

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with pregnancies and sterilization, and on the infant mortality risk. In the model, we show that the willingness to become sterilized is higher when the first-born is a boy, but this gender difference decreases with the child mortality risk. In our empirical set-up, we therefore use the interaction between the gender of the first-born and climate-driven malaria as an instrument for sterilization. Rather than controlling for malaria, we keep controlling for village fixed effects, which provides a stronger identification. Namely, the identification will rely on the fact that two women who have a male first-born and live in villages with different infant mortality will adjust the decision and timing of sterilization to these differences in infant mortality. Put differently, in a given village, a woman who has a male first-born will reduce her willingness to undergo the sterilization more than the women who have a girl first-born if the village is at a high risk of infant mortality. The model is estimated in 2SLS:

$$Y_{iv} = \alpha_0 + \theta Ster_{iv} + \beta_0 Male_{iv} + \mathbf{X}_{iv}\Lambda_0 + \delta_{0v} + \epsilon_{iv} \tag{2}$$

$$Ster_{iv} = \alpha_1 + \beta_1 Male_{iv} + \gamma_1 Male_{iv} \cdot Malaria_v + \mathbf{X}_{iv}\Lambda_1 + \delta_{1v} + \eta_{iv} \tag{3}$$

where $Male_{iv}$ is a dummy variable for the first-born's gender and $Malaria_v$ is the climate-driven malaria in the village.

Figure A3 in the Appendix displays the sterilization take-up by cohort, age, gender of the first-born and malaria prevalence. The pattern is the same throughout cohorts: in places with higher malaria, sterilization take-up is lower and, most importantly, the discrepancy between women with a male first-born and women with a female first-born is lower in those areas than in areas with high malaria risk.

4.5. Climate-driven malaria and infant mortality

Is climate-driven malaria relevant information for women who need to assess the risk of infant mortality? Given that several plans were implemented to fight malaria, actual child mortality may actually differ from that predicted for climate characteristics. However, Patel (1994) documents that mothers-in-law and, more generally, women from the previous generation influence the sterilization decision.

We first check that our malaria measure captures historical values of malaria endemicity in India. Christophers & Sinton (1926) provided one of the oldest maps depicting malaria prevalence in the 1920s. Figure A2a reproduces their map, which classifies the Indian territory into 6 categories. We have digitized this map and coded these categories from 1 (non-malarious) to 6 (highest endemicity) (see Figure A2c). We find that the correlation between climate-driven malaria and the historical prevalence is high (0.6).

We further check that our malaria measure predicts past child mortality. The first round of the DHS, collected in 1992-1993, records child mortality. We limit our sample to children born up to rank three and regress whether the child died before the age of five on the climate-driven malaria, controlling for state fixed effects and other district characteristics. Table A5 displays a positive correlation between predicted malaria and child mortality in all specifications. It

therefore seems that the climate-driven measure of malaria conveys information regarding the risk of infant mortality, which might be used by women to make their sterilization decision.

4.6. Interpretation of the estimates

It is interesting to clarify what kind of effects are taken into account with our estimations. To do so, we begin by listing the changes associated with sterilization in an OLS framework and then discuss which mechanisms are still present when one estimates the effect of sterilization with the specified instrument. Women who are sterilized a) might suffer from the surgery, b) avoid additional pregnancies and births, which could have direct and indirect effects on their health, c) avoid the use of other contraceptives, which could induce side effects, d) may intrinsically differ from the others (preferences with regards to fertility, bargaining power within the couple, etc.) and e) should have already reached their desired fertility level, which leads most of them to make this decision. It is important to recognize that d) and e) prevent us from inferring causality based on the OLS. Figure A4 in the Appendix provides women's average number of children by age and sterilization status. From this table, we see that younger women who are sterilized have a higher number of children than non-sterilized women, which comes from mechanisms d) and e). However, from age 33, the trend reverses and women who are sterilized are those who manage to keep their fertility low (b). As already mentioned, Bharadwaj (2015) finds that sterilization reduces the number of living children by 0.81. Our own estimates reach the same estimated effect.[22]

Our instrument plays on the fact that women who have a male first-born reach their desired fertility level more quickly than others (particularly when malaria is low). In order to simplify our point here, let us imagine that women decide to sterilize only when they have a male offspring.[23] Simplify even further by assuming that there is an equivalence between having a male child and becoming sterilized. Then, immediately after the first birth, women who have a male offspring become sterilized, while others do not. At this moment, women who are sterilized have the same number of children as the others. Therefore, the main effect of the sterilization is due to the surgery and its potential complications (mechanism (a)). Two to three years later, however, non-sterilized women have either increased their number of pregnancies (mechanism b) or taken other contraceptives (c). As time passes, more and more pregnancies may occur and the 2SLS estimate is an average of the effects of sterilization for different durations since sterilization. The instrumentation strategy therefore eliminates the omitted variable bias present due to mechanisms (d) and (e).

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[22]Our estimation is the following: we panelize the dataset and use one observation per woman and per year. For each year, we observe her achieved fertility and we know whether the woman has been sterilized. The effect of sterilization on fertility should depend on the years since sterilization (as more time passes, more children are avoided). To allow for this heterogenous effect, we interact the sterilization variable with the years since first birth, which is defined for all women in the sample. We also interact this last variable with woman's age. Indeed, women become less fertile when they age. Controlling for woman fixed effects, we find that, on average, women accumulate in total -0.8 children due to sterilization.

[23]The differentiation between areas of various malaria prevalence simply allows us not to assume that having a male first-born does not affect how women are treated.

Obviously, it would be of interest to assess the consequences of sterilization in light of the effect of other types of contraceptives. This assessment would entail identifying separately the mechanism (a). However, in our case, we do not have an exogenous variation for the take-up of other contraceptives and therefore can assess only the global effect of sterilization. Recall, however, that the use of other contraceptives remains extremely limited in India.

Lastly, we discuss potential selection issues. Selection might occur for two reasons: first, observed sterilized women are those who survived the surgery, but we expect this selection to be minor because the number of deaths associated with sterilization seems to be low (603 identified cases in four years between 2009 and 2012). Even though this is likely a conservative estimate of deaths due to sterilization, it has to be compared to a rough estimate of three million tubectomies performed each year.[24] The risk of death in a sterilization procedure seems therefore of the order of magnitude of 0.004 percentage points. Second, sterilized women have fewer pregnancies and deliveries and therefore a lower risk of dying at delivery or because of complications. The maternal mortality ratio in India was estimated at 414 (for 100,000 live births) in 1998 and 298 in 2004.[25] If sterilization leads to -0.81 children, then it reduces the risk of dying by 0.24 percentage points to 0.33 percentage points. In both instances, biases associated with attrition are likely extremely small.

5. Results

5.1. First stage

We first check that the interaction between the gender of the first-born and climate-driven malaria predicts female sterilization, conditional on village fixed effects and household and women's characteristics. Table 3 shows that this is the case for each sample and that the associated F-stats are high. The interpretation of the effect is the following. In the DLHS, women who have a male first-born are +9.8 percentage points more likely to become sterilized, but the effect is lower when the area is characterized by a high prevalence of (climate-driven) malaria. Essentially, the effect vanishes when the variable for malaria is equal to 0.099/0.0015=66. The malaria variable actually ranges from 0.18 to 63.7, which means that the male first-born effect is equal to 0 only when the malaria is at its maximum. The advantage of having a male first-born for a family is not considered as certain if the malaria is too prevalent in the area. Since we control for village fixed effects throughout the analysis, the effect of malaria is identified only via different decisions made by households in the same village, depending on whether they had a male or a female first-born. The effect of having a male first-born on sterilization and its heterogeneity with respect to malaria is strikingly the same when we use the DHS samples. Given that our instrument is based on a district-level predicted malaria, we allow for some correlation

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[24]Authors' computations based on figures provided by the Ministry of Health and Family Welfare, acquired through the Health Information System and `http://164.100.47.132/Annexture_New/lsq15/11/au4404.htm`.

[25]WHO, UNICEF, UNFPA, World Bank Group, and the United Nations Population Division. Estimates obtained from the World Bank website.

between error terms at the district level in the estimations.

Table 3: Prediction of sterilization - First stage

	Woman has been sterilized		
	DLHS - 2	DHS - 2	DHS - 4
	(1)	(2)	(3)
Male 1st born	0.099***	0.084***	0.085***
	(0.004)	(0.006)	(0.003)
Male 1st born x Malaria	-0.0015***	-0.0013***	-0.0014***
	(0.0001)	(0.0002)	(0.0001)
Observations	433 015	77 465	448 273
Adjusted R2	0.148	0.0713	0.112
Village FE	Yes	Yes	Yes
F-stat	156.3	33.73	179.0

Sample: women having given birth in DLHS 2 (col. 1), in DHS 2 (col. 2) and DHS 4 (col. 3). Standard errors clustered at the district level in parentheses. The provided F-stat is the value of the Fisher test in which the coefficient for Male 1st born x Malaria (d) equals 0.Controls include the age of the woman, the education level of the woman, religion, caste, and wealth. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

5.2. Effect of sterilization on health

Table 4: Consequences of sterilization

	(1)	(2)	(3)	(4)	(5)	(6)
	Symptoms	BMI	Anemia	Symptoms	BMI	Anemia
	OLS	OLS	OLS	2SLS	2SLS	2SLS
Woman has been sterilized	0.234***	0.106***	-0.028***	0.346***	-0.478	-0.136*
	(0.009)	(0.016)	(0.002)	(0.105)	(0.528)	(0.071)
Sample	DLHS 2	DHS 2 and 4		DLHS 2	DHS 2 and 4	
Observations	433 015	525 497	526 399	438 550	513 841	514 744
Mean Y	1.006	22.09	0.517	1.008	22.08	0.519

Sample: women who have given birth. Standard errors clustered at the district level in parentheses. Controls include the age of the woman, the education level of the woman, religion, caste, wealth and village fixed effects. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

We now turn to the estimates of the effects of sterilization on health. We begin with three measures of health. The first is obtained from the DLHS and is the number of declared symptoms among a list of ten: vaginal discharge, irritation, ulcers around the vulva, pain in the abdomen, swelling in the groin, lower back pain, pain and spotting during sexual intercourse, menstruation problems, fever, masses coming out of the vagina, involuntary escape of urine while sneezing or coughing, and lumps in the breast.[26] All these health issues can be symptoms of reproductive tract infections and sexually transmitted infections (and some of them may be symptoms of an obstetric fistula). The most frequently declared symptoms are lower back

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[26]These are separate questions for each symptom and are not linked to the contraception questions.

pain (20%), vaginal discharge (16%), menstruation problems (12%) and pain in the abdomen (10%). Then, most of the other health problems (irritation, pain while urinating, fever, pain during sexual intercourse, masses coming out of the vagina and involuntary escape of urine) are reported by 4 to 7% of the women who have already given birth. The other symptoms are quite rare, with less than 2% of women reporting them (ulcers, swelling in the groin, lumps in the breast, and spotting during sexual intercourse).

The second and third variables, body mass index (BMI) and anemia, are obtained from the DHS. The woman is considered anemic if her hemoglobin level is lower than 12g/dL. Among women who have already given birth, 31.5% are underweight (BMI < 18.5) and 51% are anemic.

The first three columns of Table 4 display the OLS estimates, while the last three display the 2SLS estimates. The 2SLS show that sterilization increases the prevalence of symptoms in the reproductive sphere but lowers the prevalence of anemia. Both effects are economically meaningful: the number of symptoms increases by one-third compared to the average in the sample and the prevalence of anemia decreases by 26% compared to the average. We do not identify any effect on BMI in the 2SLS, contrary to the OLS estimates. For the total number of symptoms and anemia, the 2SLS estimates are fairly close to the OLS but larger in absolute value. We will discuss the interpretation of the effect on total symptoms below once we disaggregate the effect by declared symptoms. Regarding anemia, the effect might be due to a lower number of episodes of pregnancies and breastfeeding due to sterilization: we find that, controlling for socio-economic background and village fixed effects, pregnant women and breastfeeding women have a lower hemoglobin level (-0.72 and -0.18, respectively) than the other nonsterilized women.Another channel could be that these women have reduced menstruation, to which we return below.

We now provide robustness tests to check the validity of our results. In particular, we want to control for additional covariates that may correlate with our instrument and affect the health variables. We already control for village fixed effects. Therefore, unobserved location characteristics are not a threat to our identification. However, if the climate-driven malaria correlates with other location characteristics that have a heterogenous effect by the first-born's gender on health, then our instrument would (spuriously) capture these effects. Indeed, climate-driven malaria might be correlated to wealth, health care, use of other contraceptives and intrinsic preferences regarding the number of children. The direct effect of each of these variables is captured by the village fixed effects. Now, we check whether the inclusion of an interaction between the first-born's gender and each of these characteristics changes our estimates.[27]

Table A6 in the Appendix shows this check. We confirm the main results: sterilization increases the number of total symptoms, has no effect on BMI and reduces anemia. The size of the effects is similar to the previous results. We increase the significance of the estimates when adding the interaction between the first-born's gender and the average ideal number of boys in

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[27]We compute the district-averages of health care on the DLHS, of the use of contraceptive methods and ideal number of children on the DHS, and of wealth on both datasets.

the district. However, it is not clear whether this is a valid control since malaria should affect the target number of children stated by parents. Therefore, we do not include it in the main specification.

One additional threat to our identification comes from the fact that malaria is known to increase anemia among infected people. If, in addition, women who have a male first-born are better treated in their family, then the interaction between malaria and the first-born's gender could have a direct negative effect on anemia. However, in that case, we would expect that having a boy first-born has a direct negative effect on anemia. This is not the case: the effect is -0.0037, with a p-value of 0.349.[28]

Table 5: Consequences of sterilization - 2SLS

Panel A							
	(1) Vaginal discharge	(2) Itching or irritation	(3) Boils/ulcers around vulva	(4) Pain in abdomen	(5) Pain when urinating	(6) Swelling in groin	(7) Lower back pain
Woman has been sterilized	0.067 (0.047)	0.020 (0.037)	0.007 (0.021)	0.004 (0.044)	-0.004 (0.033)	0.001 (0.021)	0.098* (0.053)
Observations	429 197	429 178	429 161	429 172	429 166	429 147	429 170
Mean Y	0.166	0.0726	0.0286	0.103	0.0645	0.0276	0.205
Panel B							
	(1) Pain during sex. interc.	(2) Spotting aft. sex.	(3) Menstrual problems	(4) Fever	(5) Mass out of vagina	(6) Escape of urine	(7) Lump in the breast
Woman has been sterilized	0.048* (0.027)	0.027** (0.014)	0.117*** (0.043)	0.027 (0.032)	0.007 (0.032)	-0.028 (0.026)	0.016 (0.014)
Observations	429 144	429 152	429 418	429 157	429 159	429 151	429 097
Mean Y	0.0450	0.00941	0.125	0.0583	0.0466	0.0434	0.0120

Sample: women who have given birth in DLHS 2. Standard errors clustered at the district level in parentheses. Controls include the age of the woman, the education level of the woman, religion, caste, wealth, whether the first-born is a boy and village fixed effects. The woman's sterilization status is instrumented by the interaction between the predicted malaria at the district level and whether the first-born is a boy. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

It is interesting to uncover what drives the effect of sterilization on total symptoms. Table 5 shows that sterilization increases the likelihood of suffering from lower back pain (+9.8 points), from pain during sexual intercourse (+4.8 points), from spotting after sexual intercourse (+2.7 points) and from menstrual issues (+11.7 points). The menstrual problem variable is itself an aggregation of several variables. We find that the effect comes mostly from an increase in excessive bleeding.[29] It is reassuring to observe that the significant effects match the stated side effects of sterilization (in the survey and in qualitative interviews with sterilized women).[30] Again,

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[28]More generally, having a boy first-born does not improve health: we do not find any effect on BMI and symptoms.

[29]The results are available upon request.

[30]In the DLHS, women are invited to select the side effects from which they suffered due to their contraception method. Table A7 in the Appendix shows that, compared to women using IUDs or pills, sterilized women are more likely to have felt unable to work (+4.6 percentage points) and to have suffered from weakness (+13.2 points), body ache or backache (+5.2 points), cramps (+1.1 points) and white discharge (+2.6 points).

these increases are meaningful since they range from an increase of 47.8% (lower back pain) to 287% (spotting after sexual intercourse). The prevalence of pain during sexual intercourse and menstrual issues are estimated to double due to sterilization. This set of results invalidates the idea that anemia is reduced because of lower menstruation flows and suggests that the main channel is the lower number of pregnancies. Table A8 provides the same robustness tests as above but for each symptom, and we find that the results are robust.

5.3. Further placebo tests

We provide further checks on the validity of our identification strategy with placebo tests. To do so, we use retrospective information on the woman's health status, which should not be impacted by the sterilization, once instrumented. Health outcomes during the last pregnancy (and therefore obviously before sterilization) are recorded in the DLHS. These variables encompass care during the last pregnancy, records of symptoms during the last pregnancy, and information on the last labor and post-delivery complications. Women's height is obtained from the DHS. Table A9 in the Appendix displays the 2SLS on the placebo variables. We find that our identification strategy is convincing at removing the endogeneity bias since we find no significant effect of sterilization on the occurrence of previous health symptoms.[31]

A final placebo check consists of testing whether we find an effect of our instrument on another woman surveyed in the household. We can test this only with the DHS sample and therefore only on the anemia variable. We implement the placebo by testing whether we find a reduced form effect of Male $\times$ Malaria on another woman than on the woman for which the first-born's gender is defined. Table A10 in the Appendix, column 1, displays the true reduced form on all women in the sample. The coefficient on the interaction is significant only at 10%, consistent with the result obtained with the 2SLS in Table 4. We lose significance when we split the sample between the woman no.1 in the sample and the following women, but the magnitude order remains similar. Column 4 provides the placebo check: we use the gender of woman no.1's first-born to predict the likelihood of being anemic for other women in the household. Both coefficients are non-significant and divided by more than 10 compared to column 3. This situation is similar to using a purely random variable for the gender of the first-born. Therefore, this placebo test confirms that our instrument does not capture spurious effects in the household.

5.4. Compliers

The sample in both datasets is large and should therefore provide some external validity to our results, at least for India. However, one threat to this external validity may come from the identification strategy if compliers have particular characteristics. In this section, we provide a characterization of the compliers. We do so by running the first-stage regression on subsamples. Women complying with the treatment are those who react more strongly to the instrument.

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[31]The OLS estimation on the placebo confirms that women in better health are more likely to undergo sterilization. The results are available upon request.

Table A11 shows that all subsamples display a correlation between the instrument and the sterilization decision, which suggests a strong external validity of our results. However, we also find that better-off, more educated, Hindu and higher-caste women tend to react slightly more than the others (columns 1 to 8). We do not find any difference depending on the quality of the health care system, nor the average use of contraceptives in the district. However, we do find that women react more to the instrument when they live in districts where the ideal number of boys is low. This finding is consistent with our model since the weight of the first-born's gender in the sterilization decision should be lower in areas where the norm is to have at least two boys than in areas where women wish to have only one boy. The results on the ideal number of girls are more difficult to interpret since they are non-monotonous. Last, we find that the women aged 25 to 35 years old are more likely to comply, which is expected, given the nature of our instrument: compliers take into account the gender of their first-born, and even if the decision does not actually take place right after the first birth, women who have given birth to many children are less likely to make their decision based on this factor. The identified effects of sterilization therefore seem to occur at a relatively young age for women. Whether effects tend to increase or fade out is a topic we assess in the next section.

5.5. Timing of the effect

Finally, we would like to check whether the effects change over time. It is important to assess whether the associations we observe are mostly transitory or persist over time. In particular, since women self-assess their own health status, it could be that they associate a recent sterilization with poorer health, attributing adverse symptoms to the surgery by mistake (even though the symptom questions are not linked to the sterilization questions). Conversely, if the process leading to sterilization increases the awareness regarding gynecological health, women would place more emphasis on gynecological symptoms. If this were the case, the association would be stronger right after the operation. We simply exploit the fact that we observe women who have undergone the surgery relatively recently. More precisely, for women who were sterilized, we know the number of years that have passed; it is censored at eight years or more (in DLHS 2). The duration since sterilization is exogenous and driven by the survey date. However, we still aim to correct for endogeneity bias due to the selection into sterilization. Given that we now have eight dummy variables (one for each duration since sterilization), we follow Wooldridge (2015) and implement a control function approach, which amounts to predicting the first stage's residual and including it as a control in the main equation.

Table A12 displays the results. The effects tend to increase in the first three years after sterilization and then remain steady. We observe a slight decline for women who became sterilized more than eight years ago, which could be due to endogenous attrition (the category 8+ includes women who were sterilized a long time ago and only healthier women survive). By comparison, the effect on anemia is very smooth. Even if sterilization is not a pure random event here, this result is important. It invalidates the hypothesis that most of the obtained effects arise from a biased assessment by the women. We therefore conclude that self-declared symptoms

do not reflect a salient memory of the operation or increased knowledge gained throughout the process.

6. Conclusion

This paper analyzes the impact of sterilization on health and highlights that sterilizations have significant effects on the health of women. Using the sample of the 430,000 Indian women who have already given birth and were surveyed in the 2002–2004 wave of the DLHS, we show that sterilizations lead to a wide range of reproductive tract infections and gynecological symptoms. We find that adverse effects are stronger three years after the operation and do not vanish over time. On the other hand, using the DHS collected in 1998–1999 and in 2015–2016 (a total of 520,000 women), we show that sterilization also improves women's health in another dimension: sterilized women have higher hemoglobin levels in a context where a large fraction of women are anemic. This shift is likely due to sterilized women having a lower number of pregnancies.

Our paper provides a decisive contribution to the literature, which has so far failed to establish causal effects of sterilizations on a large sample of women. Contrary to the existing literature, we take into account the endogeneity of the sterilization decision. We do so by implementing an innovative instrumentation strategy. We rely on the fact that women who face a lower risk of child mortality and who have already had a boy are more likely than others to become sterilized. We instrument the probability of becoming sterilized by the interaction between the gender of the first-born and an exogenous measure of child mortality, which is a predicted measure of malaria based on a climate-disease model.

Our results not only provide a unique glance at the situation experienced by nearly 182 million women in India[32] but also question the choice made by the Indian state to forcefully push one contraceptive method over others. We cannot be definitive, but our results are consistent with a situation in which the positive effects of sterilization (reduced number of childbearings) could be achieved with other contraceptive methods that have fewer side effects. Recall that sterilization is the main contraceptive method available in the Dominican Republic, Panama, Salvador, Guatemala, Colombia, Nepal, Brazil, Nicaragua and China.

Our paper also asks for more research on the efficiency of different types of contraceptives. Indeed, economists might be able to quantify the trade-offs associated with each contraceptive method with a different perspective than the one adopted by medical doctors. This approach would be useful to inform public health practitioners on the efficient bundle of tools to satisfy household needs in terms of family planning.

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[32]This figure is obtained by applying the sterilization prevalence observed in the DLHS 2 to the population of women as measured by the 2011 Census.

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Appendix A. Appendix

Appendix A.1. Additional tables and figures

Table A1: Facility where sterilization took place, follow-up and reported problems

Facility	Percentage	Follow-up after sterilization (%)	Mention problems due to sterilization (%)
Public hospital	53.1	28.4	14.8
CHC/PHC	19.4	42.2	19.6
Camp/mobile clinic	12.2	52.6	23.5
Private sector	13.8	14.8	12.9
Other	1.5	24.9	19.1
Total	100	32	16.6
Observations	158 526	158 439	158 475

Sample: sterilized women in DLHS 2.

Figure A1: Facility where sterilization took place

(a) Proportion of sterilizations performed in a public hospital   (b) Proportion of sterilizations performed in camps
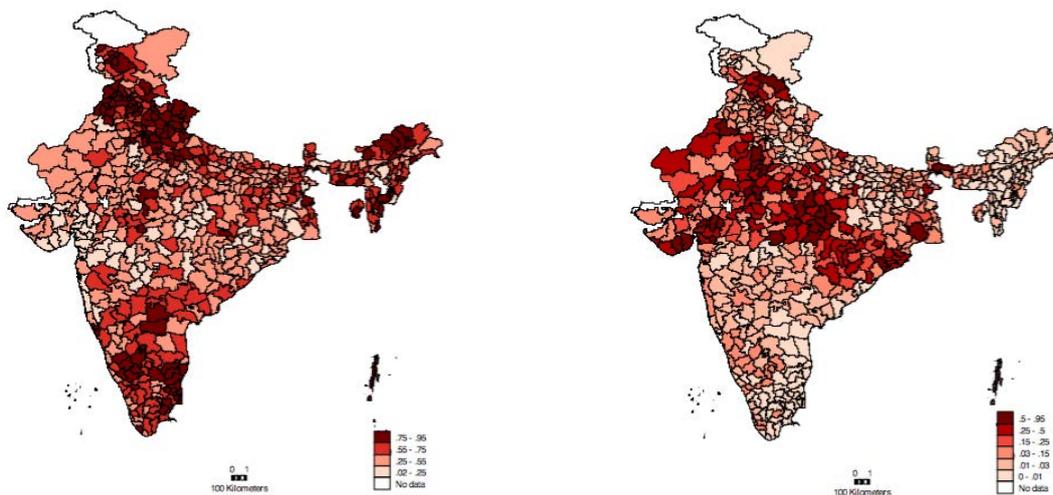
Sample: sterilized women in DLHS 2.

Table A2: Descriptive statistics

	DLHS 2	DHS2	DHS4
Women has been sterilized	0.352	0.341	0.347
Current age of respondent	30.881	32.343	34.08
Education	4.276	3.796	5.497
Hindu	0.768	0.775	0.756
Sikh	0.025	0.024	0.022
Buddhist	0.014	0.011	0.012
Christian	0.064	0.057	0.070
Muslim	0.115	0.120	0.127
Other or no religion	0.014	0.014	0.013
Scheduled caste	0.168	0.17	0.187
Scheduled tribe	0.155	0.122	0.185
Wealth	0.005	0.011	-0.046
Male first-born	0.523	0.522	0.528
Malaria (district)	24.077	24.55	24.528
Observations	450663	80853	476619

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The sample is constituted of women who have given birth.

Table A3: Problems faced by women using a contraceptive method

Method	Percentage mentioning problems with current method
Female sterilization	17%
Vasectomy	10%
No-scalpel vasectomy	11%
IUD/copper-T/loop	11%
Oral pills	12%
Condom/Nirodh	2%
Rhythm/periodic abstinence	0%
Withdrawal	0%
Other modern method	1%
Other trad. method	1%
Observations	255 180

Sample: women who are using a contraceptive method and who have given birth in DLHS 2.

Table A4: Alternatives to sterilization

Use of contraception	Percentage among women who have given birth and are not sterilized	
	DLHS 2	DHS 2 and 4
No contraception - nonpregnant women	56.51	64.44
No contraception - pregnant women	10.45	6.65
Traditional method (rhythm, periodic abstinence, withdrawal)	11.90	9.82
Condom/Nirodh	8.71	8.35
Oral pills	6.61	6.37
IUD/copper-T/loop	3.81	3.14
Male sterilization	1.60	0.9
Other modern method	0.34	0.32
Total	100	100
Observations	291 970	364 467

Sample: women who are not sterilized and who have given birth in DLHS 2 (col 1) or in DHS 2 and DHS 4 (col 2).

Figure A2: Historical malaria

(a) Malaria map for 1926
Source: Christophers and Sinton (1926)
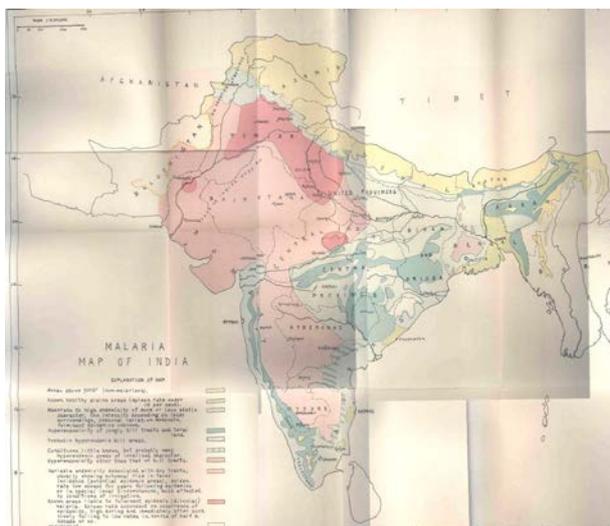
(b) Legend, zoomed.
Source: Christophers and Sinton (1926)
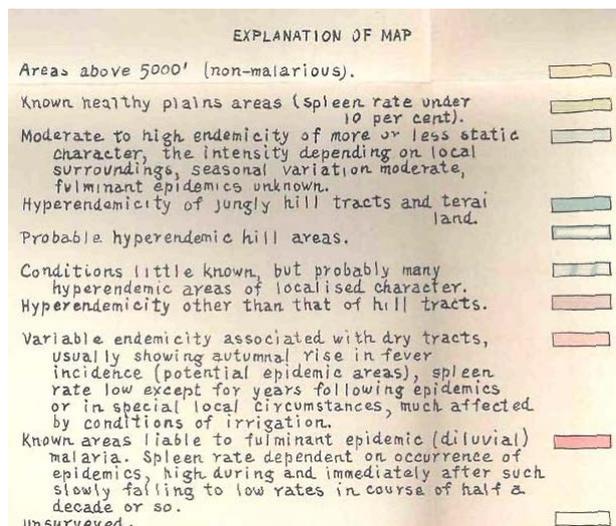
(c) Malaria prevalence in 1926
Source: Authors, using Christophers and Sinton (1926)
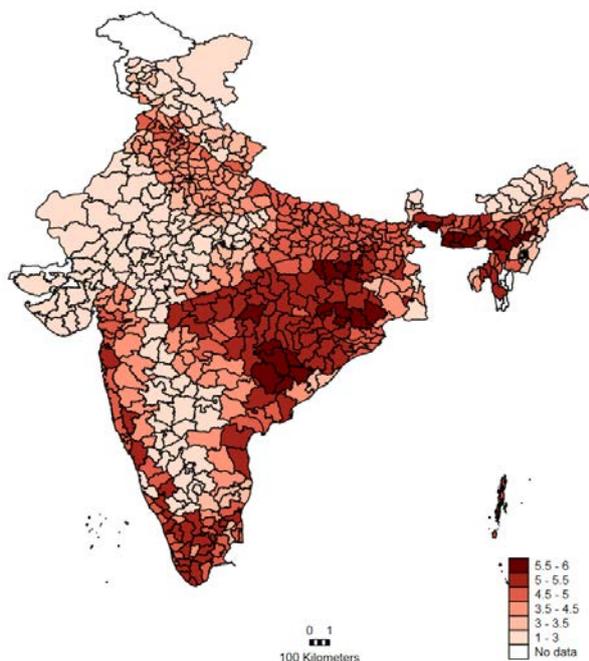
Figure A3: Probability of being sterilized by age, first-born's gender and malaria endemicity

(a) Cohort 1960-64

(b) Cohort 1965-69
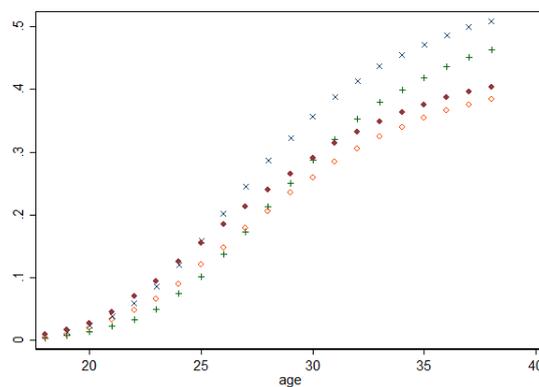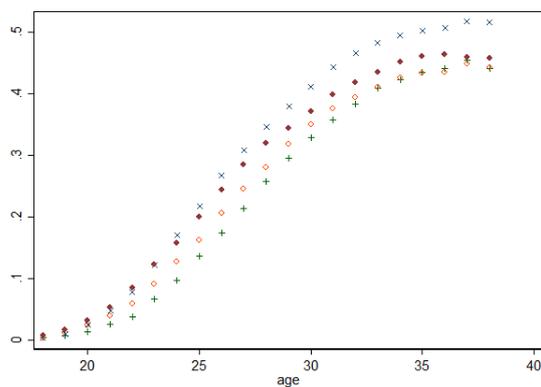
(c) Cohort 1970-74

(d) Cohort 1975-79
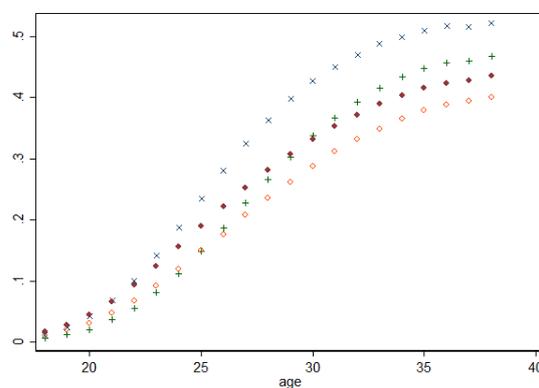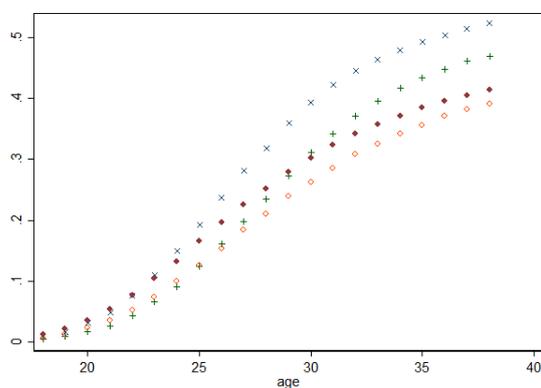
- ● male first-born, high malaria
- ○ female first-born, high malaria
- × male first-born, low malaria
- + female first-born, low malaria

Source: DHS 2 and 4, women who have given birth. High malaria districts are those with a climate-driven malaria level higher than the median.

Table A5: Malaria and historical child mortality

	(1)	(2)	(3)	(4)
Predicted malaria	0.001**	0.001**	0.001*	0.001*
	(0.000)	(0.000)	(0.000)	(0.000)
Child controls	Yes	Yes	Yes	Yes
Mother controls	No	Yes	Yes	Yes
Wealth controls	No	No	Yes	Yes
District controls	No	No	No	Yes
State FE	Yes	Yes	Yes	Yes
Observations	147169	147018	143729	143729
Adjusted R2	0.0271	0.0415	0.0444	0.0452

Sample: DHS 1, children born up to six years before the survey, up to rank three. We predict child mortality in a linear probability model. Child controls include the gender of the child and whether the child was a multiple-pregnancy baby. Mother controls include age at birth, education, religion, caste or tribe, and whether the mother belongs to a scheduled caste or tribe. Wealth controls include a wealth index built from a principal component analysis on durable goods and a dummy for rural areas. District controls include the district level wealth index and the caste/tribe composition.

Figure A4: Number of children by age and sterilization status
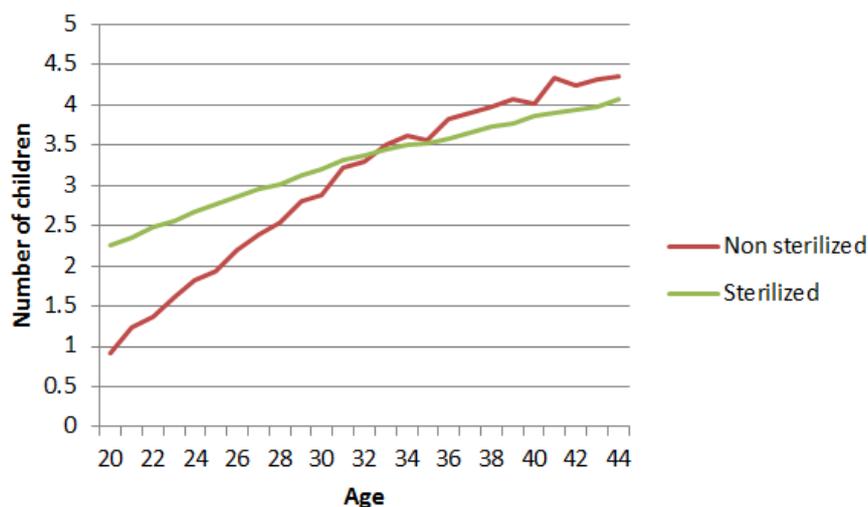
Note: the curves indicate the average number of children for women of each age, depending on sterilization status. Sample: 20–44-year-old women in DLHS 2.

Panel A: Total symptoms (Mean total symptoms = 1.01)

Control for Male x	(1) Health care	(2) Wealth	(3) District average Modern methods	(4) District average Traditional methods	(5) Ideal number of boys	(6) Ideal number of girls
Woman has been sterilized	0.385*	0.387*	0.414*	0.456**	0.423**	0.388*
	(0.207)	(0.216)	(0.212)	(0.224)	(0.211)	(0.233)
Observations	432302	432302	418757	418757	418757	418757

Panel B: BMI (Mean BMI = 22.08)

Control for Male x	(7) Health care	(8) Wealth	(9) District average Modern methods	(10) District average Traditional methods	(11) Ideal number of boys	(12) Ideal number of girls
Woman has been sterilized	-0.509	-0.278	-0.367	-0.467	-0.528	-0.638
	(0.527)	(0.552)	(0.521)	(0.526)	(0.550)	(0.598)
Observations	513128	513841	513841	513841	513841	513841

Panel C: Anemia (Mean anemia = 0.52)

Control for Male x	(13) Health care	(14) Wealth	(15) District average Modern methods	(16) District average Traditional methods	(17) Ideal number of boys	(18) Ideal number of girls
Woman has been sterilized	-0.118*	-0.184**	-0.146**	-0.137*	-0.147**	-0.162**
	(0.071)	(0.075)	(0.071)	(0.071)	(0.072)	(0.076)
Observations	514031	514744	514744	514744	514744	514744

Sample: women who have given birth. Standard errors clustered at the district level are in parentheses. The woman's sterilization status is instrumented by the interaction between the predicted malaria at the district level and whether the first-born is a boy. Controls include having a male first-born, the age of the woman, the education level of the woman, religion, caste, wealth and village fixed effects, as well as the interaction between having a male first-born and the district-level average of the variable indicated in first row. Health care is the district average of a principal-component index built on quality of heath care variables (data from DLHS). Wealth is the district average of a principal component index built on assets and durables ownership (data from DLHS and DHS). Modern method is the share of women who have already used modern contraceptives (other than sterilization) in the district (data from DHS). Traditional method is the share of women who have already used a traditional method to avoid pregnancies in the district (data from DHS). Ideal number of boys is the district average of the ideal number of boys as declared by women in the survey (data from DHS). Ideal number of girls is the district average of the ideal number of girls as declared by women in the survey (data from DHS). *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A7: Side effects of the current contraception method

Panel A	(1) Some problem	(2) Weakness/inabil. to work	(3) Bodyache/ backache	(4) Cramps	(5) Weight gain	(6) Dizziness
Reference category: Woman uses IUD/copper-T/loop or pills						
Woman has been sterilized	0.046***	0.032***	0.052***	0.011***	0.004***	0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Uses a traditional method	-0.133***	-0.046***	-0.033***	-0.008***	-0.008***	-0.048***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Husband has been sterilized	-0.029***	0.006	-0.000	-0.001	-0.008***	-0.022***
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Couple uses condoms	-0.089***	-0.022***	-0.022***	-0.003***	-0.009***	-0.027***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	252 957	252 957	252 957	252 957	252 957	252 957
Mean Y	0.119	0.0522	0.0630	0.0137	0.00738	0.0273

Panel B	(1) Nausea vomiting	(2) Breast tenderness	(3) Excessive bleeding	(4) Spotting	(5) White discharge	(6) Other problem
Reference category: Woman uses IUD/copper-T/loop or pills						
Woman has been sterilized	-0.002***	0.001***	-0.002**	0.000	0.026***	0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Uses a traditional method	-0.012***	-0.002***	-0.017***	-0.003***	-0.030***	-0.000***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Husband has been sterilized	-0.011***	-0.002***	-0.015***	-0.003***	0.006**	0.001
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Couple uses condoms	-0.009***	-0.002***	-0.017***	-0.003***	-0.013***	-0.000**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	252 957	252 957	252 957	252 957	252 957	252 957
Mean Y	0.00725	0.00313	0.0114	0.00319	0.0308	0.000399

Sample: women using a contraceptive method in DLHS 2. Linear regressions of the side effects on the type of contraceptive. Additional controls include the age of the woman, the education levels of the woman and of her husband, the age of the couple, religion, caste, wealth and village fixed effects. Standard errors clustered at the village level are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A8: Robustness to inclusion of additional controls, for each symptom

Panel A: Lower back pain

Control for Male x	(1) Health care	(2) Wealth	(3) Modern methods	(4) Traditional methods	(5) Ideal number of boys	(6) Ideal number of girls
			District average			
Woman has been sterilized	0.082	0.104*	0.114**	0.111*	0.112**	0.109*
	(0.053)	(0.054)	(0.054)	(0.057)	(0.054)	(0.060)
Observations	432054	432054	418510	418510	418510	418510

Panel B: Pain during sexual intercourse

Control for Male x	(7) Health care	(8) Wealth	(9) Modern methods	(10) Traditional methods	(11) Ideal number of boys	(12) Ideal number of girls
			District average			
Woman has been sterilized	0.048*	0.045	0.041	0.048*	0.045	0.051*
	(0.027)	(0.028)	(0.027)	(0.029)	(0.027)	(0.031)
Observations	432027	432027	418483	418483	418483	418483

Panel C: Spotting after sex

Control for Male x	(13) Health care	(14) Wealth	(15) Modern methods	(16) Traditional methods	(17) Ideal number of boys	(18) Ideal number of girls
			District average			
Woman has been sterilized	0.027**	0.025*	0.026*	0.032**	0.028**	0.027*
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.016)
Observations	432035	432035	418491	418491	418491	418491

Panel D: Menstruation issues

Control for Male x	(13) Health care	(14) Wealth	(15) Modern methods	(16) Traditional methods	(17) Ideal number of boys	(18) Ideal number of girls
			District average			
Woman has been sterilized	0.131***	0.109**	0.121***	0.118**	0.118***	0.099**
	(0.043)	(0.044)	(0.042)	(0.048)	(0.043)	(0.048)
Observations	432302	432302	418757	418757	418757	418757

Sample: women who have given birth. Standard errors clustered at the district level in parentheses. The woman's sterilization status is instrumented by the interaction between the predicted malaria at the district level and whether the first-born is a boy. Controls include having a male first-born, the age of the woman, the education level of the woman, religion, caste, wealth and village fixed effects, as well as the interaction between having a male first-born and the district-level average of the variable indicated in first row. Health care is the district average of a principal-component index built on quality of heath care variables (data from DLHS). Wealth is the district average of a principal component index built on assets and durables ownership (data from DLHS and DHS). Modern method is the share of women who have already used modern contraceptives (other than sterilization) in the district (data from DHS). Traditional method is the share of women who have already used a traditional method to avoid pregnancies in the district (data from DHS). Ideal number of boys is the district average of the ideal number of boys as declared by women in the survey (data from DHS). Ideal number of girls is the district average of ideal number of girls as declared by women in the survey (data from DHS). *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A9: Placebo: health before sterilization - 2SLS

Panel A : Long-term health and care during last pregnancy

	(1) Height	(2) Antenatal care	(3) Number of examinations
Woman has been sterilized	-0.064	-0.059	-0.407
	(0.768)	(0.145)	(0.725)
Observations	514045	187 448	187 408
Mean Y	151.9	0.656	2.559

Panel B: Health status during last pregnancy

	(1) Swelling hands, feet, face	(2) Paleness, giddiness	(3) Visual disturbances	(4) Excessive fatigue	(5) Convulsions	(6) Weak/no mov. of fetus
Woman has been sterilized	0.024	0.017	-0.117	-0.066	-0.081	-0.070
	(0.143)	(0.128)	(0.097)	(0.058)	(0.085)	(0.070)
Observations	197 383	197 383	197 383	197 383	197 383	197 383
Mean Y	0.190	0.116	0.0772	0.0193	0.0473	0.0267

Panel C: Events during last labor

	(1) Premature labor	(2) Excessive bleeding	(3) Prolonged labor	(4) Obstructed labor	(5) Breech presentation
Women has been sterilized	0.008	0.077	-0.072	-0.014	-0.107*
	(0.111)	(0.095)	(0.120)	(0.103)	(0.061)
Observations	197 383	197 383	197 383	197 383	197 383
Mean Y	0.101	0.0611	0.142	0.180	0.0257

Panel D: Post-delivery complications

	(1) High fever	(2) Abdominal pain	(3) Smelling vag. discharge	(4) Excessive bleeding	(5) Convulsion	(6) Severe headache
Woman has been sterilized	0.106	-0.130	0.065	0.132	0.012	0.124
	(0.129)	(0.138)	(0.078)	(0.092)	(0.068)	(0.125)
Observations	197 383	197 383	197 383	197 383	197 383	197 383
Mean Y	0.134	0.178	0.0503	0.0623	0.0371	0.115

Sample: women who have given birth in DLHS 2 (except for height, which comes from DHS 2 and 4). Information about most recent pregnancies is recorded only if the last pregnancy took place less than three years before the survey. Standard errors clustered at the district level in parentheses. Controls include the age of the woman, the education level of the woman, religion, caste, wealth, gender of the first-born and village fixed effects. The probability of being sterilized is instrumented by the interaction between the predicted malaria at the district level and whether the first-born is a boy. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A10: Placebo for anemia: using another child's gender

	(1) All	(2) Only women no.1	(3) Only women no.2+	(4) Only women no.2+	(5) All
Sample					
Male is the gender of the woman's first-born					
Male x Malaria	0.00019*	0.00012	0.00049		
	(0.00010)	(0.00011)	(0.00039)		
Male	-0.01530***	-0.01305***	-0.02598**		
	(0.00279)	(0.00303)	(0.01094)		
Male is the gender of woman no.1's first-born					
Male x Malaria (d)				-0.00003	
				(0.00019)	
Male				0.00408	
				(0.00492)	
Male is a random binary variable					
Male x Malaria (d)					-0.00006
					(0.00009)
Male					0.00411*
					(0.00238)
Observations	514793	454868	59925	156014	514793

Sample: indicated in first row, only DHS 4. The dependent variable is anemia. Standard errors clustered at the district level in parentheses. Controls include the age of the woman, the education level of the woman, religion, caste, wealth and village fixed effects. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A11: Compliers: First stage by subgroups

	(1)	(2)	(3)	(4)	(5)	(6)
	Wealth		Education		Religion	
	Better off	Poorer	No education	Educated	Hindu	Others
Male 1st born	-0.0017***	-0.0014***	-0.0014***	-0.0016***	-0.0015***	-0.0013***
x Malaria (d)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0002)
Observations	191629	238500	210359	219770	335268	94861
Sample	DLHS 2	DLHS 2	DLHS 2	DLHS 2	DLHS 2	DLHS 2

	(7)	(8)	(9)	(10)	(11)	(12)
	Castes		Health care quality (d)		Contraceptives use (d)	
	Lower	Higher	Better	Poorer	Low	High
Male 1st born	-0.0014***	-0.0017***	-0.0016***	-0.0016***	-0.0015***	-0.0014***
x Malaria (d)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0001)
Observations	302698	122962	212962	217167	276390	249348
Sample	DLHS 2	DLHS 2	DLHS 2	DLHS 2	DHS 2 and 4	DHS 2 and 4

	(13)	(14)	(15)	(16)	(17)	(18)
	Ideal number of boys			Ideal number of girls		
	1	2	≥ 3	1	2	≥ 3
Male 1st born	-0.0016***	-0.0011***	-0.0006**	-0.0014***	-0.0008***	-0.0010**
x Malaria (d)	(0.0001)	(0.0002)	(0.0003)	(0.0001)	(0.0002)	(0.0004)
Observations	278112	151742	28517	356269	67207	15882
Sample	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4

	(19)	(20)	(21)	(22)	(23)	
	Age ≤ 25	25 < Age ≤30	30 < Age ≤35	35 < Age ≤40	40 < Age	
Male 1st born	-0.0011***	-0.0018***	-0.0015***	-0.0012***	-0.0011***	
x Malaria (d)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	
Observations	101219	109063	97155	91240	127061	
Sample	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4	

Note: heading "Woman has been sterilized" spans all columns above.

Sample: women who have given birth. Standard errors clustered at the district level are in parentheses. Controls include the age of the woman, the education level of the woman, religion, caste, wealth and village fixed effects. (d) means that the variable is defined at the district level. *** p<0.01, ** p<0.05, * p<0.1.

Table A12: Effect of years since sterilization on health outcomes - 2SLS

	(1) Total symptoms	(2) Lower back pain	(3) Pain during sex. intercourse	(4) Spotting aft. sex.	(5) Menstrual problems	(6) Anemia
Sterilized in t	0.213	0.090*	0.036	0.021	0.053	-0.137*
	(0.210)	(0.052)	(0.027)	(0.014)	(0.043)	(0.072)
Sterilized in $t-1$	0.333	0.092*	0.041	0.023*	0.106**	-0.135*
	(0.210)	(0.052)	(0.027)	(0.014)	(0.044)	(0.071)
Sterilized in $t-2$	0.417**	0.099*	0.045*	0.027**	0.123***	-0.139*
	(0.209)	(0.052)	(0.027)	(0.014)	(0.043)	(0.071)
Sterilized in $t-3$	0.507**	0.113**	0.051*	0.026*	0.138***	-0.148**
	(0.209)	(0.052)	(0.027)	(0.014)	(0.044)	(0.071)
Sterilized in $t-4$	0.490**	0.110**	0.051*	0.025*	0.140***	-0.152**
	(0.210)	(0.052)	(0.027)	(0.014)	(0.044)	(0.071)
Sterilized in $t-5$	0.473**	0.113**	0.046*	0.025*	0.131***	-0.155**
	(0.209)	(0.052)	(0.027)	(0.014)	(0.044)	(0.071)
Sterilized in $t-6$	0.498**	0.113**	0.053*	0.025*	0.139***	-0.165**
	(0.208)	(0.052)	(0.027)	(0.014)	(0.043)	(0.071)
Sterilized in $t-7$	0.511**	0.119**	0.052*	0.026*	0.135***	-0.163**
	(0.210)	(0.052)	(0.027)	(0.014)	(0.044)	(0.071)
Sterilized in $t-8$ or before	0.386*	0.099*	0.046*	0.025*	0.116***	-0.134*
	(0.209)	(0.052)	(0.027)	(0.014)	(0.043)	(0.071)
Observations	425673	425428	425404	425411	425673	514793
Mean Y	1.005	0.204	0.0450	0.00937	0.125	0.519

Standard errors clustered at the district level in parentheses. Controls include the age of the woman, the education level of the woman, religion, caste, wealth, whether the first-born is a boy and village fixed effects. The woman's sterilization status is instrumented by the interaction between the predicted malaria at the district level and whether the first born is a boy. *** $p <0.01$, ** $p <0.05$, * $p <0.1$.

Appendix A.2. The predicted malaria variable

The measure of predicted malaria used in the instrumentation strategy originates from Lauderdale et al. (2014), who have kindly shared their data with us. Climatic conditions generate important variability in the life cycle of the mosquito, affecting both the viability of the malarial parasite and the rate of mosquito bites. As a consequence, malaria outbreaks display important seasonal variability.[33]

Lauderdale et al. (2014) use the Liverpool Malaria Model of Hoshen & Morse (2004) to simulate malaria incidence following rainfall and temperature variations. Both temperature and rainfall have a non-linear impact on epidemiological risks. The development pace of the malarial parasite within the mosquito requires approximately 111 days with a temperature above 16°C, while the rate of mosquito biting depends on cycles of 37 days with a temperature above 9°C. Above 20°C, temperature decreases adult mosquito survival. Regarding rainfall, the population of mosquitoes relies on the availability of surface water, which depends on rainfall and land-surface heterogeneity. Extremely heavy rainfall might flush mosquito larvae. As a consequence, the incidence of malaria does not linearly reflect increases in rainfall or temperature but rather reacts in a quite precise way to specific thresholds.

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[33]This is particularly the case in Orissa, West Bengal, Jharkhand (north-east India), Gujarat, Rajasthan, Madhya Pradesh and Maharashtra (north-west India).

Appendix A.3. Theoretical model of sterilization

We propose a theoretical model of the sterilization decision to guide our identification strategy. For the sake of simplicity, we assume that no woman will become sterilized before giving birth, and we represent the sterilization decision after first birth. In this model, sterilization has a direct cost on health and might generate a disutility in case of infant mortality; however, it also provides benefits through fertility control. We model the decision with three stages.

1. Stage 0: the gender of the first-born is realized.
2. Stage 1: the mother decides if she wants to become sterilized.
3. Stage 2: the mortality of the first-born is realized and, if the mother is not sterilized, her subsequent fertility is realized.

We do not differentiate between household members' utility and assume that the household is unitary. Its "final" utility is assumed as such:

$$U(B, G, P, S) = -(B - B^*)^2 - \beta(G - G^*)^2 + \gamma H(P, S) \tag{A.1}$$

where, respectively, B and G are the number of male and female children alive in the household, B^* and G^* are the desired number of male and female children for the couple, and H is the mother's health, which depends on the number of pregnancies (P) and on her sterilization status (S). There is no budget constraint in this utility maximization since the cost of additional children (compared to the desired number of children) is directly represented by the loss function in the utility. β is assumed to be lower than 1 to reflect the fact that households usually put a greater weight on achieving the desired number of boys compared to girls. γ is a parameter that reflects the utility associated with the mother's health compared the objective of reaching the desired number of male children.

We further assume that the mother's health is

$$H(P, S) = H_0 - P^2 - cS. \tag{A.2}$$

Starting from a health level H_0, the woman's health deteriorates with pregnancies (with increasing marginal costs of the pregnancies on her health) and with sterilization. We note c as the health cost of sterilization.

The decision made in stage 1 depends on the realization of the first-born's gender and on the relative expected utilities in the two cases (sterilization vs. no sterilization). B_0 is the gender of the first-born (equal to 1 if the first-born is a boy and zero otherwise). This variable is known at the moment of the sterilization decision. M_0 is the mortality of the first-born. This random variable is assumed to follow a Bernouilli distribution with expectation μ. Last, the number of additional children obtained in period 2 is also a random variable ($\tilde{N}$) with Poisson distribution with mean N. This number is not directly chosen by the household but might depend on location characteristics, such as the availability of alternative contraceptive methods, the transmission of information on how to avoid pregnancies and so on.

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We begin by computing the expected utility in stage 2, depending on whether the woman has chosen to become sterilized or not.

Expected utility without sterilization. When the woman does not become sterilized, she has additional children ($\tilde{N}$) in stage 2. These additional children are either boys ($\tilde{B}$) or girls ($\tilde{G}$). We assume an equal repartition between boys and girls. Therefore, $\tilde{B}, \tilde{G} \rightsquigarrow \mathcal{P}(\frac{N}{2})$. For a given B_0 and M_0, the household's expected utility is

$$
\begin{aligned}
EU(B_0, M_0, S = 0) =& E_{\tilde{B}, \tilde{G}} \Big[-(B_0(1 - M_0) + \tilde{B} - B^*)^2 \\
& - \beta \left((1 - B_0)(1 - M_0) + \tilde{G} - G^* \right)^2 \\
& - \gamma(1 + \tilde{B} + \tilde{G})^2 + \gamma H_0 \Big] \\
=& - \Big[(B_0(1 - M_0) - B^*)^2 + \beta((1 - B_0)(1 - M_0) - G^*)^2 + \gamma(1 - H_0) \Big] \\
& - 2(B_0(1 - M_0) - B^*)E(\tilde{B}) - 2\beta((1 - B_0)(1 - M_0) - G^*)E(G^*) \\
& - 2\gamma E(\tilde{N}) - \Big[E(\tilde{B}^2) + \beta E(\tilde{G}^2) + \gamma E(\tilde{N}^2) \Big]
\end{aligned} \tag{A.3}
$$

We then use that $E(\tilde{B}) = E(\tilde{G}) = \frac{N}{2}$ and $E(\tilde{B}^2) = E(\tilde{G}^2) = \frac{N}{2}\left(1 + \frac{N}{2}\right)$, $E(\tilde{N}^2) = N(1 + N)$. We obtain

$$
\begin{aligned}
EU(B_0, M_0, S = 0) =& - \Big[(B_0(1 - M_0) - B^*)^2 + \beta((1 - B_0)(1 - M_0) - G^*)^2 + \gamma(1 - H_0) \Big] \\
& - \left[(1 - \beta)B_0(1 - M_0) + \beta(1 - M_0) - B^* - \beta G^* + \frac{1 + \beta}{2} + 3\gamma \right] N \\
& - \left(\frac{1 + \beta}{4} + \gamma \right) N^2
\end{aligned} \tag{A.4}
$$

We now take the expectation of this expression over the mortality variable (M_0).

$$
\begin{aligned}
EU(B_0, S = 0) =& \mu EU(B_0, M_0 = 1, S = 0) + (1 - \mu)EU(B_0, M_0 = 0, S = 0) \\
=& - \gamma(1 - H_0) + (B^* + \beta G^* - \frac{1 + \beta}{2} - 3\gamma)N - \left(\frac{1 + \beta}{4} + \gamma \right) N^2 \\
& - \mu \left[B^{*2} + \beta G^{*2} \right] - (1 - \mu) \left[(B_0 - B^*)^2 + \beta(1 - B_0 - G^*)^2 + (1 - \beta)B_0 N + \beta N \right]
\end{aligned} \tag{A.5}
$$

Expected utility with sterilization. In the case of sterilization, the only random event is mortality:

$$
\begin{aligned}
EU(B_0, S = 1) =& \mu EU(B_0, M_0 = 1, S = 1) + (1 - \mu)EU(B_0, M_0 = 0, S = 1) \\
=& \gamma(H_0 - 1 - c) - \mu \left[B^{*2} + \beta G^{*2} \right] - (1 - \mu) \left[(B_0 - B^*)^2 + \beta(1 - B_0 - G^*)^2 \right]
\end{aligned} \tag{A.6}
$$

Sterilization decision. The woman becomes sterilized if and only if the expected utility differential ΔEU is positive where:

$$\Delta EU(B_0) = EU(B_0, S = 1) - EU(B_0, S = 0)$$
$$= \left(\frac{1+\beta}{4} + \gamma\right) N^2 - \left(B^* + \beta G^* - \frac{1+\beta}{2} - 3\gamma\right) N + (1 - \mu)\left[(1 - \beta)B_0 N + \beta N\right] - \gamma c$$
$$(A.7)$$

It is immediate to see that a higher health cost of sterilization (c) lowers ΔEU and, therefore, the willingness to become sterilized. This provides an immediate rationale for taking endogeneity issues into account in the identification of the effect of sterilization on health since perceived health costs may vary between women. However, the value of health (γ) has an ambiguous effect since health also deteriorates as a result of pregnancies. Therefore, we cannot predict the sign of the bias. Additionally, this last condition shows that the higher the children targets (B^*, G^*), the lower the willingness to become sterilized. This effect, however, is dampened when N is small. Last, this expression is a degree 2 polynomial function of N. Given that the term for the degree 2 is positive, this guarantees that for a sufficiently high N, women choose sterilization.

Interestingly,

$$\frac{\partial \Delta EU}{\partial B_0} = (1 - \mu)(1 - \beta)N > 0 \qquad (A.8)$$

The willingness to become sterilized is higher when the first-born is a boy, but this difference decreases with μ, the expected mortality of the first-born.

Effect of sterilization on fertility and health outcomes. The effect of sterilization on fertility is immediate: it reduces the number of pregnancies by N. The expected number of alive children is

$$E(B + G) = \mu N(1 - S) + (1 - \mu)(1 + N(1 - S)) = (1 - \mu) + N(1 - S) \qquad (A.9)$$

Hence, the effect of sterilization on the expected number of alive children is also $-N$.

In this model, sterilization has two effects on a woman's health – a direct effect ($-c$) and an indirect one – through the change in fertility. When women have one pregnancy instead of $1 + N$, their health status increases by $N(N + 2)$, given the functional assumptions.

Given the multi-dimensionality of health, we expect that the relative size of c and $N(N + 2)$ might differ depending on the health outcome. Interestingly, these effects might also change depending on the sanitary environment, the ability to monitor fertility without sterilization and the woman's age. Indeed, fertility will increase with age, while even the direct effect could vary with the time since sterilization.

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Abstract

In India, as in many developing countries, female sterilization is the main contraceptive method: 37% of women older than 25 are sterilized. However, no economic study assesses the effect of sterilization, providing guidance on efficient reproductive health policies. We analyze the consequences of sterilization for maternal health, considering the endogeneity of the decision.
We exploit that Indian households face different infant mortality risks - driven by malaria prevalence - and have a son preference. Sterilization increases when women have a boy first-born, but less so when they live in a malarious area, as they fear losing the boy; this situation provides an instrument. We show that sterilization strongly increases the prevalence of various symptoms in the reproductive sphere while also reducing the risk of anemia, likely from avoiding pregnancy. This paper is the first to assess the effect of a specific contraceptive method with a clear identification strategy.

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