THEMA

théorie économique, modélisation et applications

THEMA Working Paper n°2020-08
CY Cergy Paris Université, France

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November 2020

CY Cergy Paris Université

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Rethinking family planning policies in the developing world : evidence from sterilizations in India ⋆

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Abstract

In India, as in many developing countries, female sterilization is the main contraceptive method: 37% of women above 25 are sterilized. While no economic study provides guidance on how to implement family planning in a poor country, we analyze the consequences of sterilization for maternal health, as a hidden cost of fertility control. We instrument sterilization by interacting the first-born gender with an exogenous driver of past child mortality. We show that sterilization strongly deteriorates reproductive tract health and do not find any positive effect on nutrition. Women from lower socio-economic background and scheduled castes suffer more from the policy.

Keywords: Family planning policies; Sterilization; Health; Gender; Development.
JEL classification: I15, J13, O1, D1.

Declarations of interest: none.

⋆We are grateful to Andy Morse and Cyril Caminade for providing us with the malaria mean annual incidence as simulated by the Liverpool Malaria model (LMM).We thank Ximena Jativa for excellent research assistance. We thank Pierre André, Jean-Marie Baland, Martina Björkman Nyqvist, Guilhem Cassan, Lucia del Carpio, François Libois, Nathan Nunn, Jean-Philippe Platteau, Agnes Quisumbing, Martin Ravallion, Vijayendra Rao and Rohini Somanathan for helpful comments and suggestions. We also thank the participants to the CEPREMAP India China Conference (Paris School of Economics), UNU-WIDER Gender and Development workshop (Namur and Helsinki), the brownbag seminar at the 3ie office in New Delhi, the Development and Economics Policy Conference (Heidelberg), the DIAL Conference on Development Economics (Paris), the lunch seminar at the University of Cergy, the first Development Economics Conference in Switzerland. Lastly, we thank Ved Arya, Garima Agarwal, Aruna Bhattacharyah, Manisha Ganju, Meerambika Mahapatro, Tulsi Patel, Samiur Rahman, Sumita Sarkar, Rinki Sarkar, Jay Satia, Meeraben Shah, Sudhir Pratap Singh, as well as SAPNA and SRIJAN staff for rich, lengthy and insightful discussions on family planning policies in India. This research has benefited from funding and support from the FLASH Research project of the Swiss Cooperation and Development Center, the Labex MMEDII (ANR11-LBX-0023-01), the UNU-WIDER Gender and Development project and the Cepremap.

All the figures can be printed in black and white and kept in color online.

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1. Introduction

Debate over population control in India has reached a renewed intensity lately, as a group of parliament members is currently pushing a "population control act" which would limit births to two children per couple only, similar to the Chinese one-child policy. India's concern for demographic growth is in fact a long-standing one: the country was the first to adopt family-planning policies. The choice to rely heavily on sterilization back in the 70's is still pervasive in today's policies. India spends as much as 85% of its family planning budget on female sterilization,[1] and 37% of women above 25 years old are sterilized.[2] Many other developing countries,[3] including Brazil and China, have adopted similar strategies and female sterilization remains the main contraception available to households who wish to manage their fertility. We believe this strong emphasis on a specific contraceptive method is currently not justified by proper scientific arguments. 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. 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 provide causal effects of sterilization of women on health outcomes including gynecological issues, that are often overlooked by policy makers despite their strong impact on women well-being. We do so by using very comprehensive datasets on health and by implementing an identification strategy that relies on exogenous variations 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

[1] 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)

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

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

[4] Female sterilization is estimated to cost $4 per year, which amounts to the cost of the cheapest

sterilization must provide other relative benefits to compensate for the increased cost.

Second, we shed light on the health effects of sterilization. Sterilizations are promoted by family planning policies across the developing world, while there is no evidence that they do not have adverse consequences and that other contraceptives would not be preferable. The medical literature has pointed towards several side effects. The main consequences explored by the literature are related to the disturbance of ovarian function and to menstrual and menopausal symptoms, including menstruation abnormality, menstrual pain and dysfunctional uterine bleeding. Yet the literature has remained largely inconclusive. This may be due to its main limitation: 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 psychologically and emotionally. 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). Singh et al. (2012) observe that regrets expressed by Indian women are higher after the loss of a child. Regrets are 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 also 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, which could in turn affect her health. The most obvious one is her ability to manage her fertility. While sterilization could be substituted by other types of contraceptives and 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. Byker & Gutierrez (2016) find that a

reliable implants, and is more expensive than intra-uterine devices ($1.75 per year) and vasectomy (i.e., male sterilization, $2.25 per year).

sterilization campaign in Peru reduced fertility by almost one child six to seven years after the campaign. A reduced family size might increase income per capita and increase the ability to pay for food and health care. However, informational frictions characterizing rural labor markets might be better mitigated by a greater family size (Bharadwaj, 2015), which would limit the positive effect of the fertility reduction.

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 (Francavilla & Gianelli, 2011; Ebenstein et al., 2013). Säävälä (1999) shows that young women might adopt early sterilization to enhance their social status with respect to their mothers-in-law. To the contrary, Anukriti (2014) highlights 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.

To deal with endogeneity concerns, we instrument the choice to become sterilized by interacting two determinants of sterilization. Our instrument exploits both the preference for sons and the fact that sterilization is postponed by women when they fear losing a child. The fear of losing a child depends not only on current child mortality, but also on past child mortality (Patel, 1994). To obtain an exogenous driver of past child mortality, we build on the fact that malaria was a key determinant of infant mortality (Cogneau & Rossi, 2019). Since malaria used to be strongly determined by weather conditions, we use the climate-disease model from Lauderdale et al. (2014) to recover past malaria. Within a village with a given past child mortality risk, households also take into account the gender of their children in their sterilization decision. While households are more willing to accept sterilization when they get a boy, they tend to postpone this decision if they fear losing him. We only use the gender of the first-born, which is not manipulated by parents (Bhalotra & Cochrane, 2010). While these two variables (first-born's gender and past malaria) may not satisfy the condition to be valid instruments, the interaction term between the two, once we condition on village fixed effects and control for the gender of the first born, satisfies the required exclusion restrictions. We offer a theoretical model that justifies the choice of our instrument, discuss thoroughly its validity, and provide several tests for it.

We find that the prevalence of various symptoms in the reproductive sphere increases by 50% to more than 100% as a consequence of sterilization, while sterilization does not lead to an improvement in nutrition indicators (it does not reduce the prevalence of underweight nor anemia). Women from lower socio-economic backgrounds are more adversely affected by this policy. There is therefore a hidden cost associated to the policy, which is born only by women and in particular by women from lower castes. Our study has a strong external validity since we use two samples containing each more than 400,000 observations.

The identification of our estimates relies on the assumption that the interaction between the first-born's gender and the historical malaria, conditional on having a male first-born and on village fixed effects, has no other effect on women's health other than the one transiting through the sterilization decision. We provide several tests to justify this assumption. First, we confirm that the first-born's gender is not manipulated in India, showing that this well-established fact in the literature is still observed up to 2015. Second, a threat to our identification comes from the possibility that women who have a boy are treated differently depending on whether malaria is widespread or not. Even if Milazzo (2018) identifies negative effects for women due to giving birth to a girl, she also shows that women with a first born girl are not different than others as regards nutrition, BMI, and iron supplementation. We also find that, once we take into account the sterilization decision, the gender of the first born has no effect on our health outcome variables. This result makes it unlikely that the interaction between the first-born's gender and past malaria impacts health due to different treatment of the women. Third, we show that sterilization, once instrumented, has no effect on women's health prior to sterilization. The data provide detailed information on health care access and on health during pregnancy, during labour and right after delivery. The data also entail health dimensions which should not be affected by sterilization, like height, diabetes and tension. Sterilization, once instrumented, is not correlated with these placebo measures, suggesting that our instrument correctly deals with selection. Last, we also build measures of women status in access to health care. These measures reflect the situation at the time of the survey and might have been already impacted by sterilization. We find that our instrument has a small negative correlation with them. If anything, this would bias our estimates towards zero.

The validity of some of our results also relies strongly on the hypothesis that self-declared health measures capture well the actual health of individuals. Indeed, gynecological health and pain related measures can only be assessed through self-declared variables. To address the risk that women have a biased perception of their health due to a recent surgery, we examine when the effects start materializing after the sterilization. It is actually only three years after the surgery that women start declaring symptoms, which makes it unlikely that this is driven by a biased perception. Last, regarding our measure of historical malaria, we show that our results are robust to the use of various malaria measures and that the climate-driven malaria measure at the core of the paper proxies historical malaria, as measured from a digitized 1926 map, and correlates with past child mortality.

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.[5] 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.

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 (DHS 2) and in 2015–2016 (DHS 4). These surveys are particularly

[5]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.

interesting from the health perspective since they collect anthropometric and biological measurements of women, including height, weight and hemoglobin level.[6] 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. Family planning policies in India

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. Incentives were introduced in 1967 and, as the program gradually expanded, were never discontinued. Individuals who become sterilized receive cash incentives, while the medical facilities where the operation is performed receive additional funds. Typically, the compensation package provides cash to the individual accepting sterilization, to the various actors involved in the operation (the surgeon, anesthetist, staff nurse, and technicians), and to the person who convinced and accompanied the woman to become sterilized.

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 a High-Focus State).[7] Sterilizations performed within seven days after delivery involve an extra payment of Rs 600.[8] The compensation therefore ranges from

[6] 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.

[7] High-Focus states are Bihar, Uttar Pradesh, Madhya Pradesh, Rajasthan, Jharkhand, Chhattisgarh, Uttarakhand, Orissa, Assam, Haryana and Gujarat; non-High-Focus states are the others.

[8] Payments obtained in accredited private facilities depend on the facility.

PPP$15 to PPP$82. In our data, 92% of women sterilized in 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,[9] the main trend has not yet been reversed. The incentives provided for sterilization compared to other means of contraception remain high, not only for women but also for community health workers who do not earn a fixed salary for their activity since 2006, but are paid according to their results, which includes convincing women to become sterilized.

If we want to compare costs for contraceptives provision, we can use the payments from the state to the private accredited sector for the different acts, since they should reflect the costs. The total paid amount for a sterilization may be as high as Rs 3000, while it is only Rs 75 for an IUD insertion. If we assume that a sterilization offers contraception for 20 years on average[10] compared to five years of protection offered by an IUD, the ratio of costs is extremely unfavourable to sterilizations (Rs 150 per year against Rs 15 per year with IUDs). This result is consistent with other studies concluding that sterilization is usually costlier than other types of contraceptives and in particular compared to IUD (Wickstrom & Jacobstein, 2011; Singh & Darroch, 2012).

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

[9]The new scheme also includes the promotion of IUDs, and the compensation given for vasectomy increased. Source: `https://nhm.gov.in/images/pdf/programmes/family-planing/schemes/Enhanced_Compansation_Scheme.pdf`, last accessed January 8, 2020.

[10]This is a very optimistic hypothesis, the Guttmacher Institute uses an estimate of 13 years of protection for sterilization for the Asian region.

by less than 1% of the couples.

Table 1: Contraception method currently used by women

Any method of contraception used?	Percentage of women: 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.

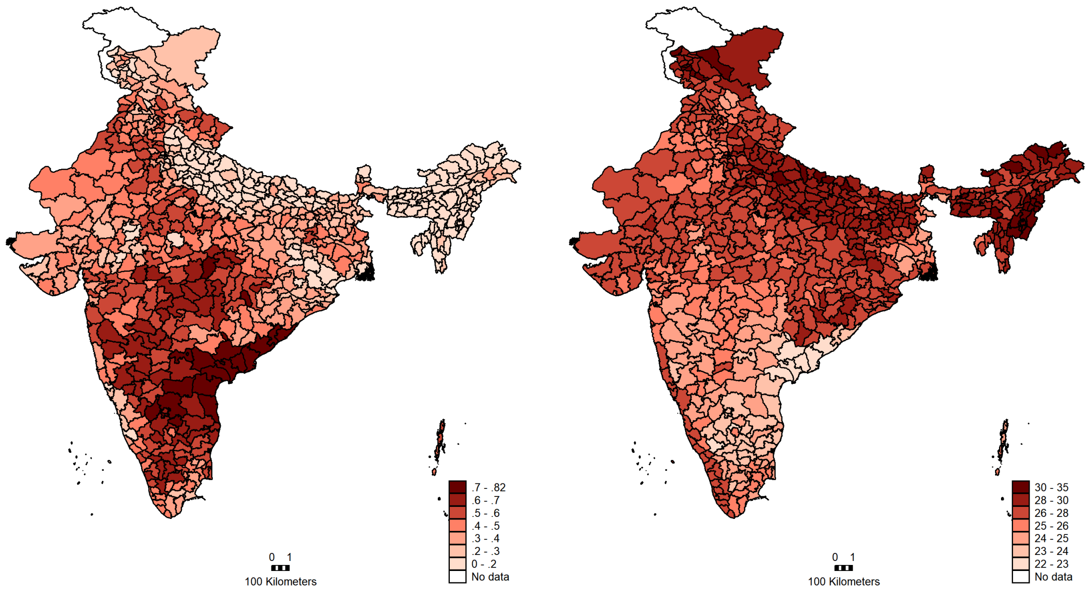
Figure 1a reports the percentage of sterilized women in the DHS 4 by district. While in some states in the north-east of India (like Uttar Pradesh), the district average is below 20%, in numerous districts located in the center and in the south-east, more than 60% of women are sterilized. In several districts of Andhra Pradesh, the percentage rises above 70%.

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).

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.

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 years old, 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

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

(a) Probability to be sterilized, by age

(b) Number of children, by age

Source: DHS 4, all sampled women.

were sterilized. Figures A1a and A1b show the proportion of women going to a public hospital 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 (reference modality) are more likely to be sterilized. Women with low education levels are more likely to be sterilized. Women from low castes or from a tribe are less likely to undergo sterilization. The effect of wealth, conditional on these characteristics, is not consistent across samples. The 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

Table 2: Probability of being sterilized

	DLHS - 2 2002-2004 (1)	DHS - 2 1998-1999 (2)	DHS - 4 2015-2016 (3)
Current age of respondent	0.066***	0.077***	0.059***
	(0.002)	(0.003)	(0.002)
Age squared	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)
education	-0.005***	-0.004***	-0.006***
	(0.000)	(0.001)	(0.000)
Sikh	-0.048***	-0.040**	-0.035***
	(0.010)	(0.019)	(0.010)
Buddhist	-0.005	0.032	0.009
	(0.011)	(0.024)	(0.007)
Christian	0.000	-0.041***	-0.014**
	(0.007)	(0.014)	(0.006)
Muslim	-0.131***	-0.145***	-0.115***
	(0.005)	(0.009)	(0.005)
Other or no religion	-0.005	-0.004	-0.030***
	(0.008)	(0.017)	(0.007)
Scheduled caste	-0.027***	-0.035***	0.004
	(0.004)	(0.007)	(0.004)
Scheduled tribe	-0.051***	-0.077***	-0.013***
	(0.005)	(0.010)	(0.005)
Other backward caste	0.002	-0.005	0.008***
	(0.003)	(0.005)	(0.003)
Wealth	-0.006***	0.007***	-0.002***
	(0.001)	(0.002)	(0.001)
Years since first birth	0.030***	0.024***	0.020***
	(0.001)	(0.001)	(0.001)
Observations	450007	80182	472616
Village FE	Yes	Yes	Yes

The regression is a linear probability model on the sterilization status. Sample: women having given birth, see details in each column. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth as well as her first-born's gender. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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. Women overwhelmingly declare more side effects associated to sterilization compared to the use of temporary contraceptives. Table A4 shows that, compared to women using IUDs or pills, sterilized women are more likely to report some problems (+4.6 percentage points). In particular, they are more likely to have felt unable to work and to have suffered from weakness (+3.2 points), body ache or backache (+5.2 points), white discharge (+2.5 points), cramps (+1.1 points) and breast tenderness (+0.1 point). As regards menstrual problems, there is no significant difference with IUD or pills, but sterilized women are more likely to experience excessive or irregular bleedings than women using condoms or traditional methods (+3 points). They are only less likely to suffer from nausea (-0.2 point).

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 A5 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. We discuss this point further when assessing the validity of the instrument. India provides us with an environment in which we can identify the effect of one type of contraceptives since few other contraceptives are used.

3.7. Expected effects of sterilization on health

Early studies from the health literature have coined a “post-tubal ligation syndrome” (Williams et al., 1951) that encompasses various symptoms, such as: abnormal bleeding and/or pain, exacerbation of premenstrual symptoms, menstrual disturbances, and/or changes in sexual behavior and emotional health. The mechanism for such effects was long debated and one possibility was that "the destruction of the fallopian tube and, (...) the concomitant destruction of portions of the mesosalpinx, alters the blood supply to the ovary. (...) Ovarian hormone levels would be affected and a variety of menstrual disorders would ensue." (Gentile et al., 1998). Since then, there have been roughly as many pieces of research that identify a negative effect of sterilization as pieces that do not find any effect (Gentile et al., 1998). However, many methodological issues have been raised, like endogenous selection, lack of control variables, absence of control for earlier use of contraceptives. Later studies have not solved these issues. Since Peterson et al. (2000), which follow a cohort of women before and after sterilization, the literature has mostly concluded that there was no negative effect. Yet endogenous selection into female sterilization is clearly visible in their baseline differences. Besides the post-tubal ligation syndrome, the health literature has identified the risk of ectopic pregnancy,[11] which has extremely severe consequences when it is not detected early enough. The literature has also stressed that sterilization may alter the ovarian function, thereby altering breast cancer and ovarian cancer risk. While tubal ligation has been associated with a reduced risk of ovarian cancer (Kreiger et al., 1999; Gaitskell et al., 2016),[12] the association with breast cancer is unclear (Irwin et al., 1988; Kreiger et al., 1999; Gaitskell et al., 2016). These studies do not deal with endogeneity. Last, tubal sterilization is also known to often lead women to opt for hysterectomy[13] years later, with no clear explanation for this choice (Peterson, 2008). To our knowledge, no article addresses the question of the effect of sterilization in a context of low-quality health care : side effects could be more pronounced due to poor hygiene and follow-up care.

In the economics literature, the focus is mostly on the effect of sterilization on reduced fertility and its consequences. For instance, Byker & Gutierrez (2016) find that the sterilization campaign in Peru led to an average reduction of fertility by 0.95

[11]If the tubes are cut but poorly closed, a spermatozoid could still meet an ovul, but with a very low probability that the egg reaches the uterus. More advances technics of surgery allow to reduce this risk but they are unlikely to be used in India.

[12]Negative associations are also found for endometrial (Kjaer et al., 2004) and cervical (Mathews et al., 2012) cancers, while the association of tubal ligation with anal cancers has been either negative (Coffey et al., 2015) or positive in the literature.

[13]Hysterectomy is the operation which consists in removing the uterus.

children and concludes that girls of sterilized mothers had higher height-for-age and boys of sterilized mothers had better schooling participation. Both results point to an improvement in the resources per person when women are better able to monitor their fertility. In addition, the compensation paid to women in case of sterilization could also have an income effect on health, but it is unlikely to be major, compared to the increase in income per capita associated to the reduction in fertility. Last, Anukriti (2014) addresses the question of the effect of sterilization on women's bargaining power. She finds that sterilization increases violence from the husband and has ambiguous effects on women's autonomy.

3.8. Outcome variables in our data

Our main analysis focuses on health outcomes that may be impacted by sterilization, according to the existing literature. We build an index for reproductive tract issues by aggregating declared symptoms in the DLHS 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.[14] Some of them may be symptoms of very severe pathologies such as obstetric fistula (masses coming out of the vagina) or breast cancer (lumps in the breast), but this cannot be established with certainty. The most frequently declared symptoms are lower back 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 average woman declares one such symptom in total.

To capture socio-economics impacts through consumption and changes in woman general health, we look at nutrition indicators. We use being underweight and being anemic as main symptoms of poor health. We obtain them from the DHS. To un-

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

derstand the impact of sterilization on nutrition, we need to take into account that non-sterilized women may be pregnant, which has a direct effect on the measurements. The definition of underweight is based on the BMI (BMI $<$ 18.5) but it does not make sense to use pregnant women since their BMI increases with pregnancy duration, without signifying an improvement in their health. As a result, we exclude pregnant women from the estimations for the underweight outcome variable. The issue with anemia is slightly different : while women who are pregnant have systematically a lower hemoglobin level (Kilpatrick & Hardisty, 1961; de Leeuw et al., 1966),[15] hemoglobin thresholds defining anemia are adjusted to the pregnancy status of the women. According to the WHO, a woman should be considered anemic if her hemoglobin level is lower than 12g/dL or 11g/dL if she is pregnant (WHO, 1968, 2011). Anemia can be further decomposed into mild, moderate and severe anemia (WHO, 2000, 2011).[16] Among women who have already given birth, 31.5% are underweight and 51% are anemic.

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 and 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

[15]In our DHS data, pregnant women have on average a hemoglobin level lower by -0.89 on an average level of 11.7g/dL. See Table A6. Breastfeeding is also associated with lower hemoglobin level but we neglect that aspect.

[16]Pregnant women with 10.0 to 10.9 g/dl and nonpregnant women with 10.0 to 11.9 g/dl of hemoglobin have mild anemia. Moderate anemia characterizes women with 7.0 to 9.9 g/dl of hemoglobin. Women with less than 7.0 g/dl of hemoglobin have severe anemia.

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 and by implementing an instrumentation strategy that we describe below. We estimate the following regression:

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

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, age squared, years of education, religion, caste (i.e. whether the woman belongs to a scheduled tribe, a scheduled caste, or to some other backward caste), wealth and years since first birth. 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 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. A wide literature supports this finding using data up to 2006 (Gupta, 1987; Bhat & Zavier, 2007; Jha et al., 2011; Anukriti et al., 2016; Milazzo, 2018) and we confirm that this still holds up to 2015.

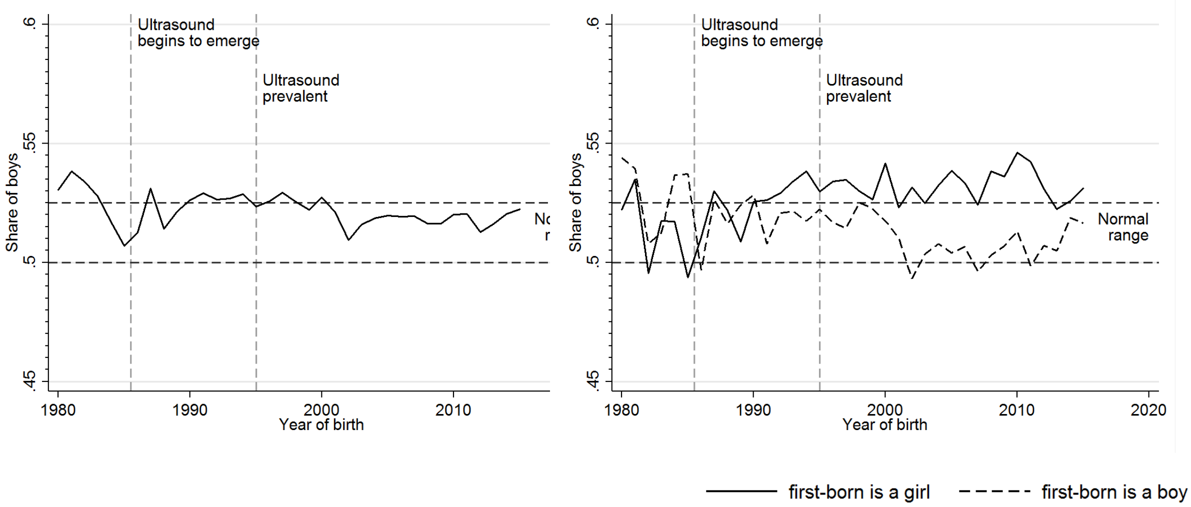
[17] Bhalotra & Cochrane (2010) find that the average household wishes to have two boys.

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' 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, receive more nutritious food, or have an easier access to healthcare, then the gender of the first-born affects both the sterilization decision and the woman's health. This concern seems to be relatively limited, as the health outcomes we focus on are either not impacted by the gender of the first born, or impacted through fertility related channels. Milazzo (2018) shows that women with a first born girl are more likely to start developping anemia two years after the first birth, and that this is the result of their fertility behaviour rather than of mistreatment. Indeed, she shows that the gender of the first born has no impact on the consumption of several types of food and on BMI, finding no evidence of discrimination in the allocation of food within

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

the houhehold. She also finds that the gender of the first born does not affect the probability to receive iron supplementation, suggesting no difference in access to basic healthcare. Last, while non educated women are more likely to experience violence within the first year following the birth of a first born girl, after one year, no difference can be observed, suggesting that domestic violence does not explain the observed effect on anemia. Despite these results, we do not exclude the gender of the first born from our specifications.

4.3. Infant mortality

We also exploit the fact that women believing to face 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 have lost a child, 12% before and 3% after they were sterilized. The loss of a child after the operation significantly increases the likelihood of regretting the operation by 5.6 percentage points and thus has a strong impact on the likelihood of expressing regrets. The effect is even bigger if the child was under five: it increases the likelihood of regretting the operation by 8.1 percentage points.[19]

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 therefore focus on a historical cause of infant mortality, and on one of its exogenous driver, so as to build a measure which does not reflect socio-economic conditions. Pathania (2014), Chang et al. (2014), Cogneau & Rossi (2019) have all shown the impact of malaria on child mortality. 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

[19]This effect is obtained from a regression of expressing regrets on (under-five) child loss, woman's age and its square, woman's education, SC/ST/OBC, religion, wealth, years since first birth and village fixed effects. The loss of a child before the operation has no effect on the likelihood of regretting the operation.

and land-surface heterogeneity (see Appendix A.2 for details). The malaria incidence predicted by the climate–disease models captures only the exogenous component of malaria prevalence, which should also be close to the historical malaria, before attempts to fight the disease. This type of model has been previously used by Oster (2012) to predict life expectancy on Africa. However, historical malaria may also be correlated with present malaria. So we do not assume its exclusion from the main regression.

We have two different measures of malaria predicted by climate–disease models, originating from Lauderdale et al. (2014) and based on two different rainfalls data sources (see Appendix A.2 for details). The malaria model, combined with rainfall and temperature time series from the latest global atmospheric reanalysis,[20] provides predicted malaria measures for the period 1981–1999. The authors also use the most reliable existing source on rainfalls, the satellite TRMM, which was launched in 1998, to compute a precise predicted malaria measure at a very fine grid (0.25°x 0.25°) over the period 1998–2010. Given the dates of our surveys, we use the 1981–1999 measure. Figure 4a displays the annual incidence of malaria as simulated by Lauderdale et al. (2014) for the period 1981–1999. Figure 4b shows the malaria endemicity as measured 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 several areas (the southern states, the eastern states) they differ markedly, reflecting their socio-economic conditions and history of malaria reduction measures.

As mentioned, we use the modeled malaria based on climate for the 1981–1999 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) and certainly not through yearly changes in the risk of malaria. Relatively rare events such as child death might be transmitted over years and maybe even generations. We return to this question below.

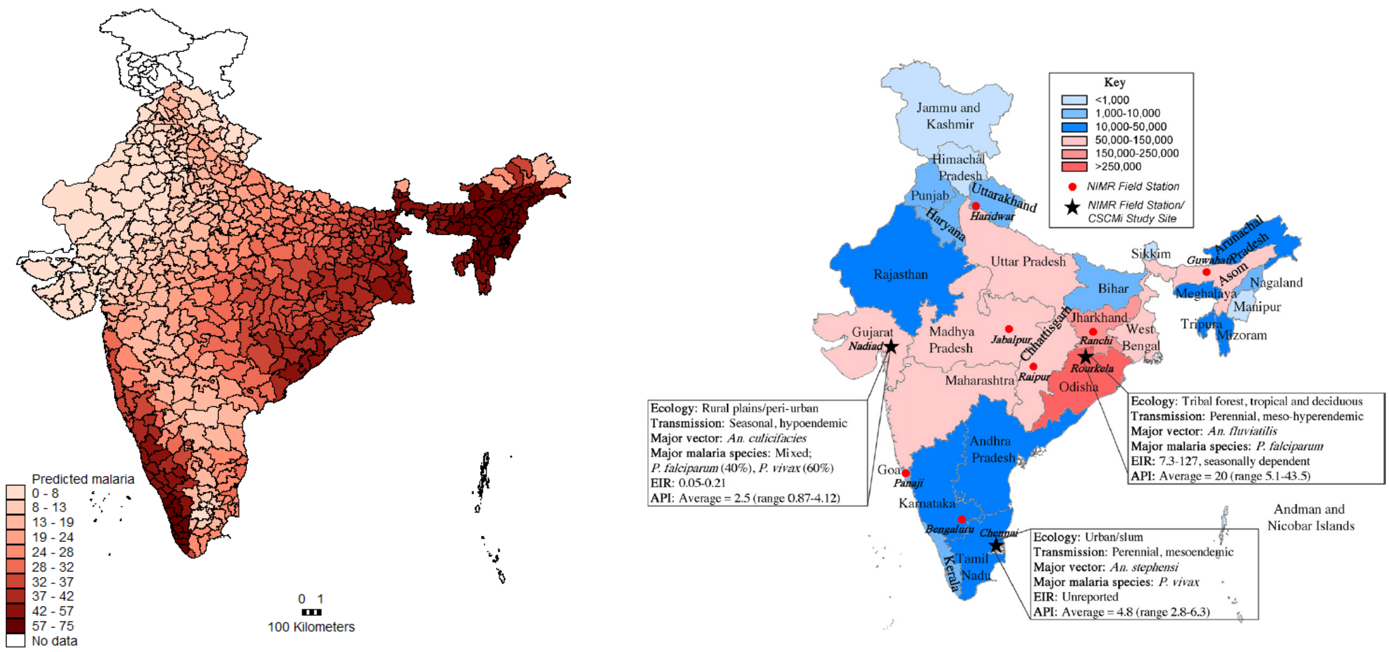
Last, the information obtained from the model is provided in grids, but we aggre-

[20] Reanalysis combines the wide range of available weather related satellite measures with a numerical model of the atmosphere, thus resulting in high quality interpolation whenever observations are scarce.

Figure 4: Past climate-driven malaria and actual malaria

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

(b) Actual malaria, in Das et al. (2012)



gate the information at the district level to be matched with our datasets.[21] 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 fear losing him. 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 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 past malaria as an

[21] See Appendix A.2 for details.

instrument for sterilization. Rather than controlling for past 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 past 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 opt for sterilization earlier than the woman who has a female first born, and even more so if she does not fear losing him. The gap in the timing of the sterilization decision will be more pronounced when the risk of infant mortality is low.

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

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

where $Male_{iv}$ is a dummy variable for the first-born's gender and $Malaria_v$ is the past 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 predicted past malaria prevalence. The pattern is the same throughout cohorts: in places with higher past 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 low malaria risk.

4.5. Historical malaria, 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 malaria differs from the one predicted by climate characteristics. However, Patel (1994) documents that mothers-in-law and, more generally, women from the previous generation influence the sterilization decision. Moreover, rare events such as child death might be transmitted over generations. Past determinants of child mortality are thus likely to explain 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 (rank correlation equal to 0.52).

We further check that our malaria measure predicts past child mortality. The first round of the DHS, collected in 1992-1993, records child mortality for all ever born children, and provides information for roughly 250 000 children, whose median year of birth is 1982. Table A7 shows that an increase by one standard deviation of the malaria measure increases by 1.3 percentage points child and infant mortality rates. The effect is sizeable, given that 13.2% of recorded children died before the age of 5, and 8.8% before the age of one. Such an effect is plausible given the estimations provided in the literature.[22] 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

Before turning to the results, 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).

[22]For instance, in Africa, while malaria control in 2000-2015 has halved malaria prevalence (Bhatt et al., 2015), it has also decreased infant mortality by 25% to 50% in malarious areas (Cogneau & Rossi, 2019).

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 and Byker & Gutierrez (2016) that the fertility is reduced by 0.95 children six to seven years after sterilization. Our own estimates conclude to a reduction by 1.48 children once fertility is completed and a reduction by 0.81 when women are 30 years old (see section 5.8).

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).

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 allow identifying separately the mechanism (c). 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. One remaining question is whether the instrument acts on the use of other contraceptives and we address it below.

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

[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.

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 sterilizations 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, 298 in 2004 and 200 in 2010.[25] If sterilization leads to 1.48 fewer children, then it reduces the risk of dying by between 0.3 percentage points (1.48*0.2) and 0.6 percentage points (1.48*0.414, with the 1998 figure). This is likely a lower bound - as it does not take into account other maternal morbidity factors like abortion or short birth spacing intervals. Yet biases associated with attrition are small.

5. Results

5.1. First stage

We first check that the interaction between the gender of the first-born and climate-driven past 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.[26] The interpretation of the effect is the following. In the DLHS, women who have a male first-born are +10.34 percentage points more likely to become sterilized, but the effect is lower when the area was characterized by a high prevalence of (climate-driven) malaria. Essentially, the effect vanishes when the variable for malaria is equal to 0.1034/0.0015=68.9. The malaria variable actually ranges from 0.28 to 74.7, which means that the male first-born effect is equal to 0 essentially when the malaria is at its maximum.[27] The advantage of having a male first-born for a family is not considered as certain if malaria was too prevalent in the area. Since we control for village fixed effects throughout the analysis,

[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.

[26] This F-stat is the Fisher statistic associated to the test of the hypothesis $H_0 : \gamma_1 = 0$.

[27] 2% of the districts display a predicted malaria prevalence above 68.9.

Table 3: Prediction of sterilization - First stage

	DLHS - 2	DHS - 2	DHS - 4
	Woman has been sterilized		
	(1)	(2)	(3)
Male 1st born	0.1034***	0.0847***	0.0879***
	(0.0032)	(0.0054)	(0.0032)
Male 1st born x Malaria	-0.0015***	-0.0011***	-0.0013***
	(0.0001)	(0.0002)	(0.0001)
Observations	439694	77632	457130
F-stat	287	48	286
Village FE	Yes	Yes	Yes

Sample: women having given birth in DLHS 2 (col. 1), DHS 2 (col. 2) and DHS 4 (col. 3). The regression is a linear probability model on the sterilization status. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

the effect of past 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 very similar when we use the DHS samples. Given that our instrument is based on a district-level predicted malaria, we allow for some correlation between error terms at the district level in the estimations.

5.2. Effect of sterilization on health

We now turn to the estimates of the effects of sterilization on health. 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 and has no effect on the likelihood of being anemic or underweight. The effect on symptoms is economically meaningful: the number of symptoms increases by 42.5% compared to the average in the sample. The comparison of the OLS and the 2SLS estimates points to a positive selection into sterilization. We will discuss the interpretation of the effect on total symptoms below once we disaggregate the effect by declared symptoms. The absence of effect on nutrition indicators is striking: it means that, despite the reduction in the number of dependents, women fail to benefit from the increased resources. We see two possible explanations.

Table 4: Consequences of sterilization

	Symptoms OLS (1)	Underweight OLS (2)	Anemia OLS (3)	Symptoms 2SLS (4)	Underweight 2SLS (5)	Anemia 2SLS (6)
Woman has been sterilized	0.195***	-0.008***	-0.011***	0.425**	-0.057	-0.064
	(0.009)	(0.001)	(0.002)	(0.192)	(0.040)	(0.064)
Mean Y	.99	.2	.51	1	.2	.51
Observations	450003	517049	536046	438982	500094	518376
Pregnant women	Yes	No	Yes	Yes	No	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Sample	DLHS 2	DHS 2 and 4		DLHS 2	DHS 2 and 4	

Sample: women having given birth, see details in each column. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth as well as her first-born's gender. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

First, there might not be an increase in resources: Bharadwaj (2015) shows that children actually provide labor, which reduces the hiring and supervision needs of the household. Alternatively, if resources increase, women may not be able to benefit from them.

One threat to our identification comes from the fact that past malaria could have an impact on women's health that could differ with the gender of the first-born child. This would be the case if women who have a male first-born are better treated in their family, and this translates into a better access to resources, among which health care. However, this would bias our estimates towards zero. Second, as already discussed above, Milazzo (2018) has shown that women who have a male first born are not different in terms of BMI, nutrition, and iron supplementation. The main difference is that they are less likely to engage in fertility behaviours that are detrimental to their health (including a high number of pregnancies and short birth spacing intervals). As a result, they are less likely to suffer from anemia and to die at young ages. We confirm her findings. Regarding anemia, once we control for the sterilization decision, thus controlling for the channel she highlights, the effect of having a first born male on anemia is not significant anymore. We observe a similar pattern for gynecological health. Further, we also find that having a male first born has no direct effect on underweight. Results are displayed in Table A12.

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.[28]

Table A8 in the Appendix shows this check. We confirm the main results: sterilization increases the number of total symptoms, and we fail to identify a consistent and significant effect on being underweight and anemia. The size of the effects is similar to the previous results.

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 (+9.3 points) and from menstrual issues (+16.1 points). 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). Again, these increases are meaningful since they range from an increase by 44% (lower back pain) to 123% (menstrual problems). Note, however, that the sum of the effects on these two symptoms is far from the estimate of the total effect, which suggests that other health issues might be positively affected. Candidates are spotting after sexual intercourse and lump in the breast, which are significant at the 10% level. The size of the coefficients suggests large effects with a doubling of the prevalence of the symptom due to sterilization compared to the mean. Table A9 provides the same robustness tests as above but for these four symptoms, and we find that the results are robust. We also checked (Table A10) that removing the pregnant women from the control group does not change the

[28]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.

Table 5: Consequences of sterilization: symptoms - 2SLS

	Vaginal discharge	Itching or irritation	Boils/ulcers around vulva	Pain in the abdomen	Pain when urinating	Swelling in groin	Lower back pain
Woman has been sterilized	0.059	0.011	0.003	0.011	-0.016	0.011	0.093**
	(0.042)	(0.033)	(0.018)	(0.039)	(0.029)	(0.018)	(0.047)
Observations	438758	438739	438722	438733	438727	438708	438732
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	.17	.073	.029	.1	.065	.028	.21

	Pain during sex. interc.	Spotting aft. sex.	Menstrual problems	Fever	Mass out from vagina	Escape of urine	Lump in the breast
Woman has been sterilized	0.027	0.020*	0.161***	0.012	0.008	-0.005	0.024*
	(0.024)	(0.011)	(0.040)	(0.027)	(0.030)	(0.022)	(0.013)
Observations	438705	438713	438982	438716	438720	438712	438657
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	.045	.0095	.13	.058	.047	.043	.012

Sample: women having given birth in DLHS 2. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth and her first-born's gender. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses.

results.

Last, we use the hemoglobin and BMI information and assess whether different cut-offs change the pattern (Table A11).

These additional tests provide only one significant result: sterilization seems to reduce overweight but the estimate is only significant at the 10% level. We do not find any effect on anemia nor malnutrition.

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 care and health status, which should not be impacted by the sterilization, once instrumented. This allows us to check that our exclusion restriction is not threatened by direct effects on health or by the behavior of health care practitioners. Antenatal care and health outcomes during the last pregnancy (and therefore obviously before sterilization) are recorded in the DLHS. These variables encompass frequency and timing of care received during the last pregnancy, records of health symptoms during the last pregnancy, and information on delivery complications. Women's height is obtained from the DHS. Table A14 displays the 2SLS on the placebo variables. We find no significant effect of sterilization on the occurrence of previous health symptoms and on the intensity of antenatal care, despite the number of tests.

Second, we look at health dimensions which should not, according to the medical literature, be affected by sterilization: glucose level and arterial tension (Table A13). We do not find any impact of sterilization on diabetes and arterial tension.

Our identification strategy may also be threatened if households use other types of contraceptives than sterilization in response to the exogenous variation. Table A15 tests whether the instrument acts on the other types of contraceptives, as well as on traditional methods. We do find that the interaction between having a male first born and living in a historically malarious area impacts the use of other types of contraceptives. However, the effect is fairly small and is clearly dominated by an increased use of traditional methods. In addition, among the modern methods, the use of condom is the only one significant at the 5% level. Condoms do not, a priori, have side effects and therefore the instrument does not affect health through this channel. The increased use of pill is only significant at the 10% level, it is of the opposite sign and the point estimate is extremely small (a twentieth of the effect on sterilization). This therefore cannot explain our results.

Last, the instrument may also create changes in the woman's status within the household if having a son elevates status, but to a lesser extent if the son is considered as more likely to die. In order to evaluate if this is the case, we use the DHS variable on women's ability to access health care and the issues they face. We first build an index of status in which we aggregate the detailed information: whether obtaining permission to seek health care is a problem, whether obtaining money, using transportation, going alone or not having access to a female provider for health care is a problem. Table A16 indicates that the instrument happens to be correlated with two of the variables. However the instrument has a (small) negative effect on woman's status. If this effect is not due to sterilization (which we cannot test), then it tends to bias our 2SLS estimate but the bias on symptoms is downwards (and we provide a lower-bound of the true effect).

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.

Table A17 shows that all subsamples display a correlation between the instrument and the sterilization decision, which suggests a strong external validity of our results. In particular, the coefficients are the same by wealth categories, and by education levels; we find that higher-caste women tend to react slightly more than the others, maybe reflecting their stronger preference for male offspring. We do not find any difference depending on the quality of the health care system, and only to a low extent with the average use of contraceptives in the district. However, we do find that women react more to the instrument when their ideal number of boys is low. This finding is consistent with our theoretical model since the weight of the first-born's gender in the sterilization decision should be lower for women who wish to have at least two boys than for women who 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, a recent surgery could make health issues more salient. 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 A18 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). This result 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.

5.6. Heterogenous effects

Given that women with different characteristics react to the instrument, we may explore the heterogeneity of the effect of sterilization on women's health. In particular, we expect more adverse outcomes for women of lower socio-economic background. Indeed, these women tend to use more often sterilization camps than private facilities for the surgery and probably have less follow-up care. We focus on the number of total symptoms to evaluate this heterogeneity and use again the control function approach. Table A19 shows that women of scheduled castes have significantly more adverse consequences of sterilization than higher castes (the effect increases by 11%). This is also the case for other backward castes, but not for scheduled tribes. Similarly, women who have more education tend to suffer less from adverse consequences: one additional year of education decreases the effect by 3%. Living in a rural area and living in a locality where the health care quality score is below the median is also a strong predictor of increased impacts. This set of results highlights the importance of taking into account the environment when choosing to promote some specific contraceptives over others: side effects (or lack of them) established in developed economies may not be sufficient to fully understand the comparative advantages of the various methods in a poorer context.

Given the high correlation between being poor, uneducated, living in a rural area, and benefiting from a low health care quality, these results are somewhat difficult to interpret. We therefore provide an additional analysis where we assess the role of women characteristics in subgroups defined by the women environment. Table A20 shows that the adverse effect of poor background (measured by being from a low caste, be it scheduled or other backward caste) is more pronounced in a poorer environment. Indeed, we find that women from low castes getting sterilized have more adverse effects in areas with poor health care quality than in areas with better health quality (column 2 vs. 1), in rural areas than in urban areas (column 4 vs. 3), in places where most of sterilization surgeries are done in camps rather than in other facilities (column 6 vs. 5). It therefore seems that more vulnerable populations are more adversely affected by the policy which consists in pushing sterilization over other types of contraceptive methods.

5.7. Alternative malaria measures

As previously mentioned, we have another measure of malaria, which has a higher precision but is computed on the climate observed in 1998–2010 period. Alternatively, we can also use the measured obtained in Christophers & Sinton (1926) to build our instrument. We do so in Table A21. In each specification, our instrument predicts the sterilization decision but clearly the noise in the 1926 measure leads to imprecise estimates. However, the point estimates provided in column 4 for the two alternative instruments are strikingly similar to the ones obtained in our main specification.

5.8. Fertility effects

One of the main positive expected impacts of sterilization is the reduction in fertility. Given that we failed to identify clear positive impacts on women's health, we check that we nevertheless identify this reduction in fertility with our identification strategy. In our specification, we want to take into account heterogenous effects due to duration. Indeed, women who were sterilized five years ago have not yet fully benefited from the reduction in total fertility. To do so, we interact the effect of sterilization with the duration since first birth (which is defined for the whole sample, contrary to the duration since sterilization). This allows us to compute the reduction in fertility at different ages: women have their first birth around 19 years old, with only a slight difference for women who opt for sterilization and those who do not. Our identification therefore exploits both the instrument (for differences in incentives to opt for sterilization) and the duration since the choice was made (due to a sampling of women of different ages). As earlier, we implement a control function approach. Given that we compare women of different ages, we allow the instrument to vary with years since first birth as well in the first-stage.[29] Table A22 shows that each year passing after first birth reduces by 6 percentage points the probability to give birth, for women who will be sterilized at some point.

If women start their fertility when 19 years old, then the women who get sterilized have $-0.181 - (30 - 19) * 0.062 = -0.81$ children (less) when they reach 30 years old. We can consider that women reach their complete fertility around 40 years old in India (see Figure 1b). At this age, they have $-0.181 - (40 - 19) * 0.062 = -1.48$ children (less) than the ones who do not get sterilized. We do not want to emphasize too much these results since other factors might be relevant to refine our estimation (for instance, women do not have the same fecundity at different ages), but this result confirm that we identify a negative impact of sterilization on fertility.

6. Conclusion

This paper analyzes the impact of sterilization on health and highlights that sterilizations have significant and adverse effects on the health of women. Using the sample of the 440,000 Indian women who have already given birth and were surveyed in the 2002–2004 wave of the DLHS, we show that sterilizations increase the prevalence of 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. Using the DHS collected in 1998–1999 and in 2015–2016 (a total of 520,000

[29] This allows to have heterogenous effects of the instrument on sterilization decision depending on cohorts: we do find that older women were more sensitive to the instrument, maybe because the actual malaria at the time of their decision was better proxied by our climate-driven measure.

women), we show that sterilization does not lead to an improvement in nutrition, as measured by anemia and underweight, despite an established reduction in fertility. We also find that women from lower socio-economic background and facing poorer health care suffer more from the adverse consequences of sterilization. More precisely, women from low economic background suffer more from poor health quality, which highlights that this question is particularly relevant for the developing world and should be taken into account when designing family planning policies.

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[30] but also question the choice made by the Indian government 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 pregnancies) could be achieved with other contraceptive methods that have fewer side effects. The Indian case may not be ideal to assess health effects of the use of modern contraceptives outside sterilization (IUD and oral pills) since few women use those methods. However, the declared side-effects associated to these methods are 40% lower than for sterilization. There is therefore scope for improving women's wellbeing by offering a more varied basket of contraceptives. More generally, the results question the widespread use of sterilization in the developing world: 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 con-

[30]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.

traceptives. 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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Appendix A. Appendix

Appendix A.1. Additional tables and figures

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

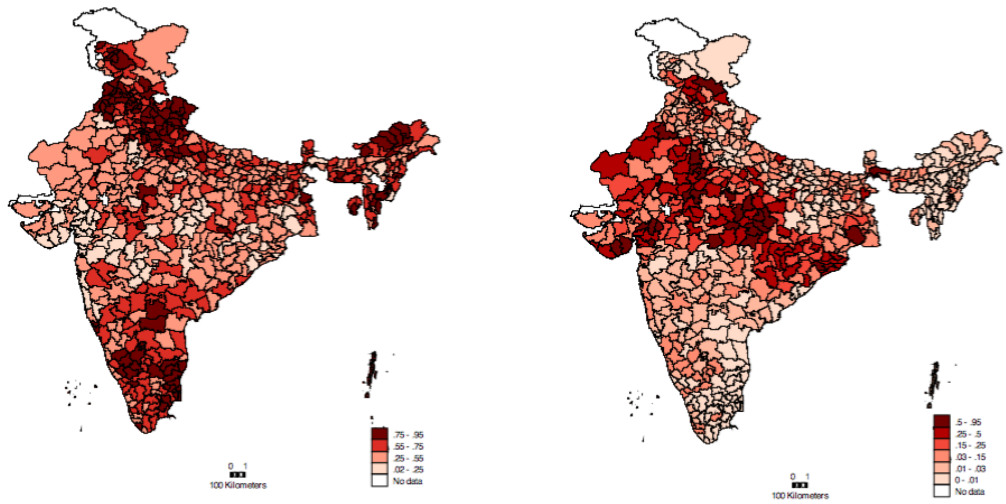
Facility	Percentage	Follow-up after sterilization (%)	Mention problems due to sterilization (%)
Public hospital	53.1	28.4	14.8
CHC/PHC	19.4	42.2	19.6
Camp/mobile clinic	12.2	52.6	23.5
Private sector	13.8	14.8	12.9
Other	1.5	24.9	19.1
Total	100	32	16.6
Observations	158 526	158 439	158 475

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 (years)	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	0.179
Scheduled tribe	0.155	0.122	0.178
Other backward caste	0.376	0.288	0.395
Wealth	-0.009	0.011	-0.046
Male first-born	0.524	0.522	0.528
Years since firt birth	12.4	14.2	14.5
Malaria (1981-1999)	29.03	29.14	29.56
Observations	450663	80853	476619

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The sample is constituted of women who have given birth. The information on predicted malaria is missing for Jammu and Kashmir, which implies around 12000, 2500 and 15000 missing observations in DLHS, DHS 2 and DHS 4 respectively. Wealth is a principal component index built from durable goods and house characteristics, with some variations depending on available variables in each dataset. Wealth index takes into account car, bike, moto possession, house drinking source, toilet facility and rural location in all datasets. In addition, durable goods include sewing machine and TV in DLHS 2, refrigerator and mattress in DHS 2 and 4. House characteristics include house type, cooking fuel and lighting source in DLHS 2, and house type in DHS 4.

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: Side effects of the current contraception method

	Some problem	Weakness/inabil. to work	Bodyache/ backache	Cramps	Weight gain	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***	0.001
	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Husband has been sterilized	-0.026***	0.008*	0.002	-0.001	-0.008***	-0.021***
	(0.005)	(0.004)	(0.004)	(0.002)	(0.001)	(0.002)
Couple uses condoms	-0.090***	-0.022***	-0.022***	-0.003***	-0.009***	-0.027***
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Uses a traditional method	-0.135***	-0.047***	-0.034***	-0.008***	-0.008***	-0.048***
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
Observations	255107	255107	255107	255107	255107	255107
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	.12	.053	.064	.014	.0075	.028

	Nausea vomiting	Breast tenderness	Irregular/excessive bleeding	Spotting	White discharge	Other problem
Reference category: Woman uses IUD/copper-T/loop or pills						
Women has been sterilized	-0.002**	0.001***	-0.002	0.000	0.025***	0.000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)
Husband has been sterilized	-0.011***	-0.002***	-0.029***	-0.003***	0.006**	0.001
	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.001)
Couple uses condoms	-0.009***	-0.002***	-0.032***	-0.003***	-0.014***	-0.000**
	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)
Uses a traditional method	-0.012***	-0.003***	-0.034***	-0.004***	-0.031***	-0.000***
	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)
Observations	255107	255107	255107	255107	255107	255107
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	.0073	.0031	.021	.0032	.031	.0004

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 A5: 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).

Table A6: Impact of pregnancies and breastfeeding on hemoglobin level

	All (1)	One child (2)	Two children (3)	Three children (4)
Currently pregnant	-0.8911***	-0.7576***	-0.8586***	-1.0165***
	(0.0164)	(0.0221)	(0.0266)	(0.0371)
Currently breastfeeding	-0.1287***	-0.0047	-0.0838***	-0.1520***
	(0.0075)	(0.0170)	(0.0130)	(0.0180)
Mean hemoglobin	11.72	11.69	11.74	11.72
Mean anemia	0.51	0.50	0.50	0.51
Observations	519678	98788	165599	116445
Adjusted R2	0.019	0.032	0.015	0.015
Village FE	Yes	Yes	Yes	Yes

Sample: women having given birth in DHS 2 and 4. Standard errors clustered at the district level in parentheses. In column (1), we use all observations; in column (2) we use only women with one child, column (3) with two children and column (4) with three children. Controls include the age of the woman, the education level of the woman, religion, caste, years since first birth, wealth. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

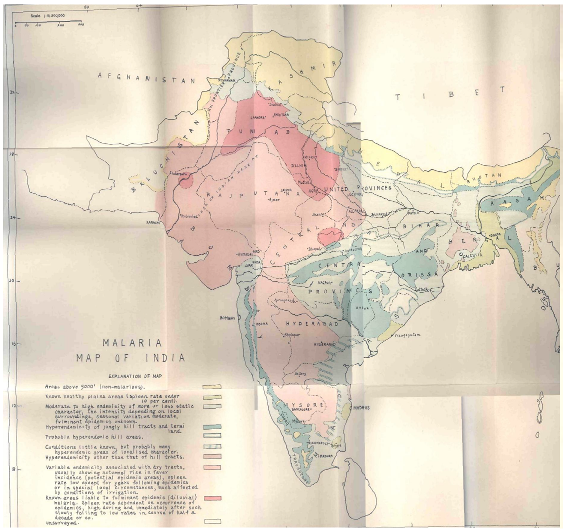
Table A7: Malaria and child mortality - Sample : DHS 1

	Under 5 mortality (1)	Under 5 mortality (2)	Under 5 mortality (3)	Infant mortality (4)	Infant mortality (5)	Infant mortality (6)
Predicted malaria	0.0006**	0.0008***	0.0007***	0.0006***	0.0007***	0.0007***
	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
District controls	No	Yes	Yes	No	Yes	Yes
Hh current wealth	No	No	Yes	No	No	Yes
Observations	199485	199485	194905	244868	244868	239216
State FE	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	0.132	0.132	0.132	0.0880	0.0880	0.0881
Effect of one sd of malaria	0.0110	0.0137	0.0130	0.0113	0.0132	0.0129

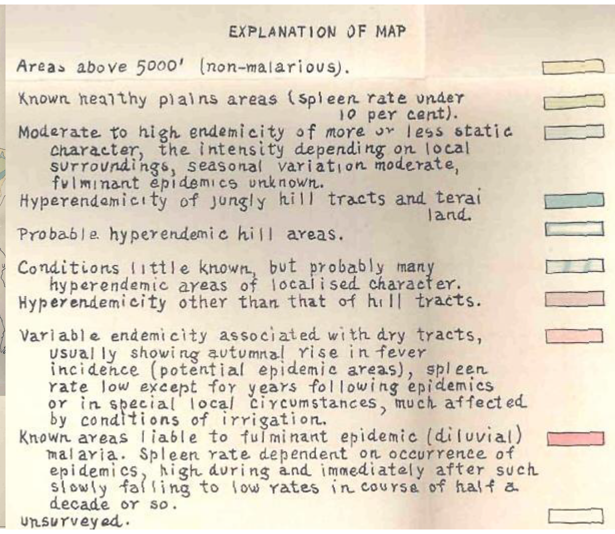
Sample : children ever born from surveyed women in the DHS 1. Controls include child gender, birth rank, interaction gender X rank, multiple birth status, rural area, religion, SC/ST ; caste (10 categories) or tribe (10 categories); mother's age at marriage, age at child birth, education (6 categories), whether was born in a village; District controls include population, SC population, ST population, illiterate population in 1991 (census), district average of wealth, of age at marriage (DHS 1) ; Hh wealth is a principal component index built from house characteristics and durable goods (bike, motorcycle, car, fan, refrigerator, sewing machine, radio and tv); Infant mortality is mortality within first year of life. Sample in columns(1)-(3) : children born up to six years before the survey; sample in columns (4)-(6) : children born up to two years before the survey. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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)

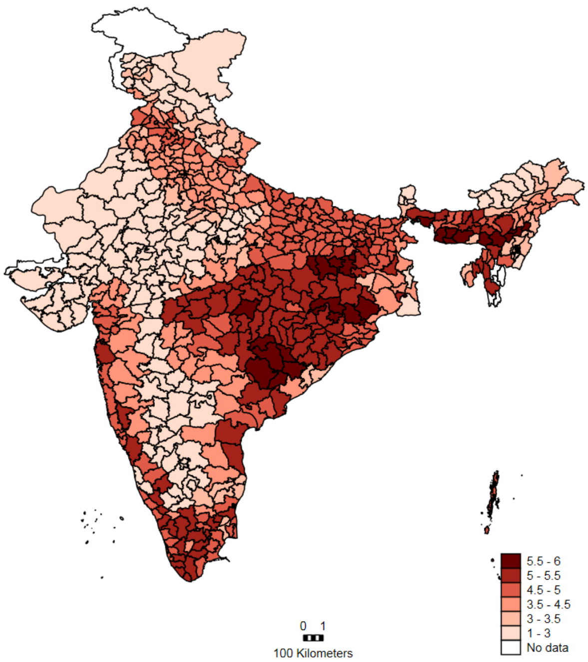
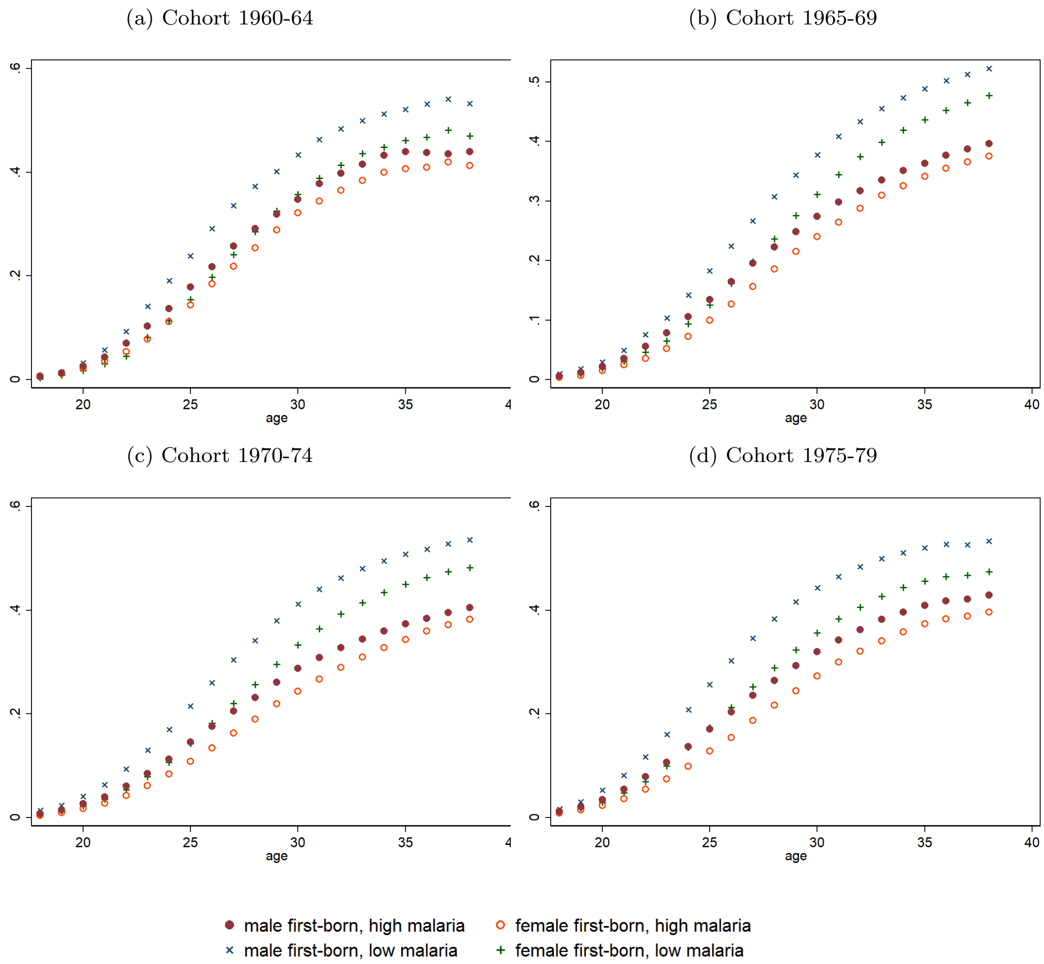
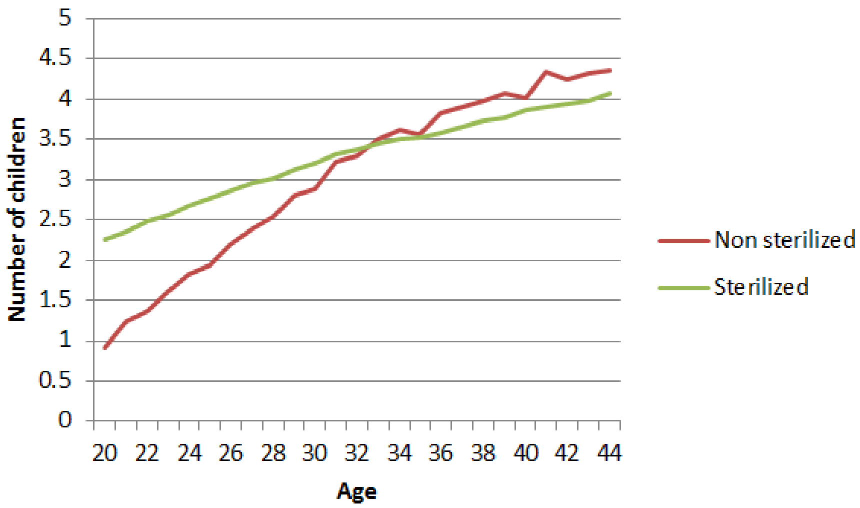


Figure A3: Probability of being sterilized by age, first-born's gender and past malaria endemicity



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

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.

Table A8: Robustness to inclusion of additional controls

Panel A: Total symptoms (Mean total symptoms=1)						
	(1)	(2)	(3)	(4)	(5)	(6)
Control for			District average			
Male x	Health care	Wealth	Modern methods	Traditional methods	Ideal number of boys	Ideal number of girls
Woman has been sterilized	0.424**	0.422**	0.419**	0.460**	0.446**	0.385*
	(0.192)	(0.194)	(0.191)	(0.198)	(0.196)	(0.210)
Observations	438982	438982	438982	438982	425268	425268
Pregnant women	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: Underweight (Mean underweight=0.2)						
	(1)	(2)	(3)	(4)	(5)	(6)
Control for			District average			
Male x	Health care	Wealth	Modern methods	Traditional methods	Ideal number of boys	Ideal number of girls
Woman has been sterilized	-0.059	-0.061	-0.056	-0.057	-0.043	-0.038
	(0.040)	(0.038)	(0.040)	(0.039)	(0.041)	(0.044)
Observations	499398	500094	500094	500094	500094	500094
Pregnant women	Yes	Yes	Yes	Yes	Yes	Yes

Panel C: Anemia (Mean anemia=0.51)						
	(1)	(2)	(3)	(4)	(5)	(6)
Control for			District average			
Male x	Health care	Wealth	Modern methods	Traditional methods	Ideal number of boys	Ideal number of girls
Woman has been sterilized	-0.057	-0.087	-0.065	-0.060	-0.077	-0.092
	(0.065)	(0.065)	(0.064)	(0.064)	(0.065)	(0.067)
Observations	517663	518376	518376	518376	518376	518376
Pregnant women	Yes	Yes	Yes	Yes	Yes	Yes

Sample: women having given birth. 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 the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth as well as her first-born's gender. We also control for the interaction between having a male first-born and the district-level average of the variable indicated in the 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 2). Modern method is the share of women who have already used modern contraceptives (other than sterilization) in the district (data from DHS 2 and from DLHS for 26 districts). Traditional method is the share of women who have already used a traditional method to avoid pregnancies in the district (data from DHS 2 and from DLHS for 26 districts). 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 2). Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A9: Robustness to inclusion of additional controls

Panel A: Menstrual problems (Mean outcome =0.13)						
Control for			District average			
Male x	Health care	Wealth	Modern methods	Traditional methods	Ideal number of boys	Ideal number of girls
Woman has been sterilized	0.166***	0.156***	0.161***	0.167***	0.153***	0.140***
	(0.040)	(0.039)	(0.040)	(0.042)	(0.040)	(0.041)
Observations	438982	438982	438982	438982	425268	425268
Pregnant women	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: Lower back pain (Mean outcome=0.20)						
Control for			District average			
Male x	Health care	Wealth	Modern methods	Traditional methods	Ideal number of boys	Ideal number of girls
Woman has been sterilized	0.090*	0.099**	0.094**	0.097**	0.112**	0.100*
	(0.047)	(0.047)	(0.047)	(0.049)	(0.048)	(0.052)
Observations	438732	438732	438732	438732	425019	425019
Pregnant women	Yes	Yes	Yes	Yes	Yes	Yes

Panel C: Spotting after intercourse (Mean outcome=0.0095)						
Control for			District average			
Male x	Health care	Wealth	Modern methods	Traditional methods	Ideal number of boys	Ideal number of girls
Woman has been sterilized	0.021*	0.018	0.020*	0.022*	0.020*	0.015
	(0.011)	(0.011)	(0.011)	(0.012)	(0.012)	(0.013)
Observations	438713	438713	438713	438713	425000	425000
Pregnant women	Yes	Yes	Yes	Yes	Yes	Yes

Panel D: Lump in the breast (Mean outcome=0.012)						
Control for			District average			
Male x	Health care	Wealth	Modern methods	Traditional methods	Ideal number of boys	Ideal number of girls
Woman has been sterilized	0.024*	0.029**	0.025*	0.023*	0.023*	0.026*
	(0.013)	(0.014)	(0.013)	(0.013)	(0.014)	(0.015)
Observations	438657	438657	438657	438657	424945	424945
Pregnant women	Yes	Yes	Yes	Yes	Yes	Yes

Sample: women having given birth. 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 the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth and her first-born's gender. We also control for the interaction between having a male first-born and the district-level average of the variable indicated in the 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 2). Modern method is the share of women who have already used modern contraceptives (other than sterilization) in the district (data from DHS 2 and from DLHS for 26 districts). Traditional method is the share of women who have already used a traditional method to avoid pregnancies in the district (data from DHS 2 and from DLHS for 26 districts). 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 2). Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A10: Consequences of sterilization: symptoms, only non pregnant women - 2SLS

	Vaginal discharge	Itching or irritation	Boils/ulcers around vulva	Pain in the abdomen	Pain when urinating	Swelling in groin	Lower back pain
Woman has been sterilized	0.061	0.012	0.010	0.026	-0.026	0.008	0.095**
	(0.042)	(0.033)	(0.018)	(0.040)	(0.029)	(0.019)	(0.047)
Observations	408619	408605	408591	408602	408593	408576	408601
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	.17	.072	.028	.1	.063	.028	.21
	Pain during sex. interc.	Spotting aft. sex.	Menstrual problems	Fever	Mass out from vagina	Escape of urine	Lump in the breast
Woman has been sterilized	0.019	0.019	0.154***	0.013	0.008	-0.008	0.020
	(0.024)	(0.012)	(0.043)	(0.028)	(0.030)	(0.023)	(0.013)
Observations	408573	408582	408831	408585	408588	408582	408531
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y	.045	.0095	.13	.059	.047	.043	.012

Sample: women having given birth in DLHS 2. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth and her first-born's gender. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses.

Table A11: Consequences of sterilization on anemia and nutrition indicators - 2SLS

Panel A : Other anemia indicators			
	Mild/moderate /severe anemia	Moderate/severe anemia	Severe anemia
	(1)	(2)	(3)
Woman has been sterilized	-0.064	-0.046	-0.001
	(0.064)	(0.037)	(0.011)
Mean Y	.51	.13	.0099
Observations	518376	518376	518376
Pregnant women	Yes	Yes	Yes
Village FE	Yes	Yes	Yes

Panel B : Other nutrition indicators				
	BMI	Moderate/severe malnutrition	Severe malnutrition	Overweight
	(1)	(2)	(3)	(4)
Woman has been sterilized	-0.399	0.008	-0.030	-0.092*
	(0.481)	(0.029)	(0.020)	(0.050)
Mean Y	22	.08	.033	.22
Observations	500094	500094	500094	500094
Pregnant women	No	No	No	No
Village FE	Yes	Yes	Yes	Yes

Sample: women having given birth, see details in each column. Mild anemia characterizes pregnant women with 10.0 to 10.9 g/dl and nonpregnant women with 10.0 to 11.9 g/dl of hemoglobin. Anemia is moderate if the hemoglobin level is comprised between 7.0 and 9.9 g/dl and severe if the hemoglobin level is lower than 7.0g/dl. A woman suffers from moderate malnutrition if her BMI is comprised between 16 and 17, and she suffers severe malnutrition if her BMI is lower than 16. She is overweight if her BMI is higher than 25. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth as well as her first-born's gender. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A12: First born gender and maternal health - 2SLS

	Symptoms (1)	Underweight (2)	Anemia (3)
Male first born	-0.003 (0.012)	0.004 (0.002)	-0.005 (0.004)
Mean Y	1	.2	.51
Observations	438982	500094	518376
Pregnant women	Yes	No	Yes
Village FE	Yes	Yes	Yes
Sample	DLHS 2	DHS 2 and 4	

Sample: women having given birth, see details in each column. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth as well as sterilization. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A13: Consequences of sterilization on diabetes and arterial tension - 2SLS

	High glucose (1)	Tension: mildly high or more (2)	Tension: moderately high or more (3)	Tension: abnormal (4)
Woman has been sterilized	0.054 (0.041)	0.100 (0.067)	0.056 (0.058)	0.015 (0.047)
Mean Y	.047	.51	.27	.13
Observations	214858	431687	431687	431687
Pregnant women	No	No	No	No
Village FE	Yes	Yes	Yes	Yes

Sample: women having given birth in DHS 4. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth as well as her first-born's gender. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A14: Placebo: health care and health status before sterilization - 2SLS

Panel A: Long-term health and antenatal care during last pregnancy						
	(1)	(2)	(3)	(4)	(5)	(6)
	Height	Antenatal care	1st visit in 1st trimester	1st visit in 3rd trimester	Nb visits to health facility	Nb visits by health worker
Woman has been sterilized	0.389	0.040	-0.055	0.084	0.091	0.301
	(0.688)	(0.105)	(0.126)	(0.066)	(0.534)	(0.264)
Observations	522975	192358	192343	192343	192234	192378
Mean Y	152	.71	.38	.069	2.6	.42
Panel B: Health status during last pregnancy						
	(1)	(2)	(3)	(4)	(5)	(6)
	Swelling hands feet, face	Paleness, giddiness	Visual disturbances	Excessive fatigue	Convulsions	Weak/no mov. of fetus
Woman has been sterilized	0.020	-0.090	-0.090	-0.067	-0.084	-0.040
	(0.105)	(0.099)	(0.071)	(0.043)	(0.057)	(0.051)
Observations	192358	192358	192358	192358	192358	192358
Mean Y	.2	.12	.082	.02	.05	.028
Panel C: Problems during delivery						
	(1)	(2)	(3)	(4)	(5)	(6)
	Premature labor	Excessive bleeding	Prolonged labor	Obstructed labor	Breech presentation	Other problem
Woman has been sterilized	-0.011	0.051	0.010	-0.023	-0.039	0.039
	(0.078)	(0.064)	(0.091)	(0.072)	(0.041)	(0.036)
Observations	192358	192358	192358	192358	192358	192358
Mean Y	.11	.064	.15	.19	.027	.026

Sample: women having given birth in DLHS 2 (except for height, that comes from DHS 2 and 4). Information about last pregnancies is recorded only if the last pregnancy took place less than three years before the survey. 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 the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth as well as her first-born's gender. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A15: Impact of the instrument on the use of other contraceptives

	No Contraception (1)	Traditional Method (2)	Other modern Method (3)	Pill (4)	IUD	Condom
Male 1st born	-0.06999***	-0.07582***	-0.01170***	-0.00298***	-0.00087	-0.00878***
	(0.00293)	(0.00294)	(0.00211)	(0.00097)	(0.00091)	(0.00160)
Male 1st born x Malaria	0.00094***	0.00103***	0.00027***	0.00007*	0.00002	0.00021***
	(0.00008)	(0.00008)	(0.00006)	(0.00004)	(0.00003)	(0.00004)
Observations	534762	534762	534762	534762	534762	534762
Adjusted R2	0.080	0.084	0.038	0.010	0.007	0.027
Village FE	Yes	Yes	Yes	Yes	Yes	Yes

Sample: women having given birth in DHS 2 and 4. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth and years since first birth.
Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A16: Impact of the instrument on women's status: health care

	Index	There is no problem with :				
	(1)	(2) Permission	(3) Money	(4) Transport	(5) Going alone	(6) No female provider
Male 1st born	0.0225***	0.0048*	0.0070***	0.0025	0.0069***	0.0013
	(0.0082)	(0.0025)	(0.0025)	(0.0023)	(0.0024)	(0.0024)
Male 1st born x Malaria	-0.0004	-0.0001*	-0.0001	0.0000	-0.0002**	-0.0000
	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	457130	457130	457130	457130	457130	457130
Mean Y	2.2	.62	.44	.37	.47	.32
Village FE	Yes	Yes	Yes	Yes	Yes	Yes

Sample : women having given birth in DHS 4. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth and years since first birth. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A17: 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						
x Malaria	-0.0014***	-0.0015***	-0.0015***	-0.0014***	-0.0014***	-0.0012***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	219848	219846	215879	223815	342613	97081
Sample	DLHS 2	DLHS 2	DLHS 2	DLHS 2	DLHS 2	DLHS 2

	(1)	(2)	(3)	(4)	(5)	(6)
	Castes		Health care quality (d)		Contraceptives use (d)	
	Lower	Higher	Better	Poorer	Lower	Higher
Male 1st born						
x Malaria	-0.0014***	-0.0017***	-0.0015***	-0.0014***	-0.0012***	-0.0014***
	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	309550	125493	219840	219854	273743	261019
Sample	DLHS 2	DLHS 2	DLHS 2	DLHS 2	DHS 2 and 4	DHS 2 and 4

	(1)	(2)	(3)	(4)	(5)	(6)
	Ideal number of boys			Ideal number of girls		
	1	2	≥ 3	1	2	≥ 3
Male 1st born						
x Malaria	-0.0015***	-0.0010***	-0.0006***	-0.0014***	-0.0008***	-0.0009***
	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0003)
Observations	283262	153697	28881	361897	68427	16083
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

	(1)	(2)	(3)	(4)	(5)
	Age ≤ 25	$25 <$ Age ≤ 30	$30 <$ Age ≤ 35	$35 <$ Age ≤ 40	$40 <$ Age
Male 1st born					
x Malaria	-0.0011***	-0.0016***	-0.0014***	-0.0010***	-0.0010***
	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Observations	103198	110815	98700	92705	129344
Sample	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4	DHS 2 and 4

Sample: see last line of each panel, women having given birth. (d) means that the variable is defined at the district level. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth as well as her first-born's gender. Village fixed effects are included in all the columns. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A18: Effect of years since sterilization on health outcomes - 2SLS

	Total symptoms (1)	Lower back pain (2)	Spotting aft. sex. (3)	Menstrual problems (4)	Lump in the breast (5)
Sterilized in t	0.213	0.086*	0.016	0.095**	0.025*
	(0.195)	(0.047)	(0.012)	(0.040)	(0.014)
Sterilized in t - 1	0.325*	0.086*	0.018	0.148***	0.025*
	(0.196)	(0.047)	(0.012)	(0.040)	(0.014)
Sterilized in t - 2	0.406**	0.093**	0.022*	0.165***	0.027**
	(0.194)	(0.047)	(0.012)	(0.040)	(0.013)
Sterilized in t - 3	0.495**	0.107**	0.021*	0.179***	0.028**
	(0.194)	(0.047)	(0.012)	(0.040)	(0.014)
Sterilized in t - 4	0.471**	0.102**	0.020*	0.179***	0.029**
	(0.195)	(0.047)	(0.012)	(0.041)	(0.014)
Sterilized in t - 5	0.458**	0.105**	0.020*	0.172***	0.029**
	(0.195)	(0.048)	(0.012)	(0.040)	(0.014)
Sterilized in t - 6	0.476**	0.106**	0.020*	0.179***	0.029**
	(0.195)	(0.047)	(0.012)	(0.040)	(0.014)
Sterilized in t - 7	0.490**	0.111**	0.021*	0.175***	0.032**
	(0.196)	(0.048)	(0.012)	(0.041)	(0.014)
Sterilized in t - 8 or before	0.408**	0.098**	0.020*	0.163***	0.029**
	(0.195)	(0.047)	(0.012)	(0.040)	(0.013)
Observations	434752	434949	434931	435196	434878
Mean Y	1	.2	.0094	.13	.012

Standard errors clustered at the village level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Controls include age of the woman, education level of the woman and of her husband, age of the couple, religion, caste, wealth, years since first birth. Standard errors corrected for the 2 step procedure (Blockbootstrap of 500 replications).

Table A19: Sterilization and reproductive tract infections symptoms : heterogeneous effects - 2SLS

	Castes (1)	Education (2)	Rural (3)	Healthcare quality (4)
Woman has been sterilized	0.398**	0.299*	0.380**	0.381**
	(0.191)	(0.174)	(0.192)	(0.190)
Woman sterilized x Scheduled caste	0.044**			
	(0.018)			
Woman sterilized x Scheduled tribe	0.002			
	(0.021)			
Woman sterilized x Oth. backw. caste	0.032**			
	(0.015)			
Woman sterilized x Education		-0.009***		
		(0.001)		
Woman sterilized x Rural area			0.058***	
			(0.013)	
Woman sterilized x Low healthcare score (< median)				0.093***
				(0.019)
Observations	439694	439694	439694	439694
Mean Y	1	1	1	1
Village FE	Yes	Yes	Yes	Yes

Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Controls include age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth and her first born's gender. Standard errors corrected for the 2 step procedure (Blockbootstrap of 500 replications).

Table A20: Sterilization and reproductive tract infections symptoms : heterogeneous effects - 2SLS

	High healthcare quality (1)	Low healthcare quality (2)	Lives in urban area (3)	Lives in rural area (4)	% camps under average (5)	% camps above average (6)
Woman has been sterilized	0.343	0.522*	0.691	0.320*	0.382*	0.359
	(0.248)	(0.304)	(0.482)	(0.195)	(0.226)	(0.375)
Woman steril. X Scheduled caste	0.013	0.071**	-0.013	0.062***	0.014	0.089***
	(0.021)	(0.028)	(0.028)	(0.023)	(0.023)	(0.027)
Woman steril. X Scheduled tribe	0.010	-0.012	-0.003	-0.005	-0.022	0.028
	(0.025)	(0.032)	(0.043)	(0.022)	(0.029)	(0.029)
Woman steril. X Oth. backw. caste	0.003	0.049**	0.022	0.035*	0.025	0.042*
	(0.018)	(0.022)	(0.021)	(0.019)	(0.021)	(0.021)
Observations	219250	220681	142200	297731	267579	172352
Mean Y	.91	1.1	.9	1.1	.99	1
Village FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Controls include age of the woman and its square, the education level of the woman, religion, caste, wealth, years since first birth and her first born's gender. Standard errors corrected for the 2 step procedure (Blockbootstrap of 500 replications).

Table A21: Sterilization, symptoms and alternative measures of malaria

Panel A : 1926 measure of malaria				
	Sterilization	Symptoms	Sterilization	Symptoms
	First stage	2SLS	First stage	2SLS
	(1)	(2)	(3)	(4)
Male 1st born x Malaria	-0.004**		-0.004**	
	(0.002)		(0.002)	
Woman has been sterilized		0.226		0.445
		(0.945)		(1.036)
Mean Y		.99		.99
Observations	447471	446749	447471	447471
F-stat	6		4.9	
District FE	No	No	Yes	Yes
Village FE	Yes	Yes	No	No
Panel B : 1998-2010 measure of malaria				
	Sterilization	Symptoms	Sterilization	Symptoms
	First stage	2SLS	First stage	2SLS
	(1)	(2)	(3)	(4)
Male 1st born x Malaria	-0.002***		-0.002***	
	(0.000)		(0.000)	
Woman has been sterilized		0.379*		0.421**
		(0.210)		(0.211)
Mean Y		1		1
Observations	439021	438310	439021	439021
F-stat	154		156	
District FE	No	No	Yes	Yes
Village FE	Yes	Yes	No	No

Sample : women having given birth in DLHS 2. Controls include the age of the woman and its square, the education level of the woman, religion, caste, years since first birth, wealth as well as her first-born's gender. Standard errors clustered at the district level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A22: Effect of years since sterilization on the number of children - 2SLS

	Number of children
Woman has been sterilized	-0.181
	(0.346)
Years since first birth	0.196***
	(0.011)
Woman has been sterilized × Years since first birth	-0.062***
	(0.002)
First stage residual	1.109***
	(0.347)
Observations	439683
Mean Y	2.8

Sample : women having given birth in DLHS 2. Standard errors clustered at the village level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Controls include the age of the woman and its square, the education level of the woman, religion, caste, wealth. Standard errors corrected for the 2 step procedure (Blockbootstrap of 500 replications).

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.[31]

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.

Rainfalls and temperature originate from the Interim European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis - hereafter ERAI. Reanalysis data combine meteorological observations with a numerical model of the global atmospheric circulation, allowing high quality interpolation in areas with fewer observations. ERAI relies on a wide range of satellite observations : it includes clear-sky radiance measurements from polar-orbiting and geostationary sounders and imagers, atmospheric motion vectors derived from geostationary satellites, scatterometer wind data and ozone retrievals from various satellite-borne sensors (see Dee et al. (2011) for extensive details on ERAI, involved data and model parametrization). ERAI is the latest global atmospheric reanalysis and covers the period since 1979 with a spatial resolution of 1.5°x 1.5°. The malaria measure used in the main specifications relies on ERAI rainfalls and temperature time series over the period 1981–1999.

The alternative malaria measure relies on rainfalls data provided by the Tropical

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

Rainfall Measuring Mission (TRMM), which has a fine grid of $0.25° \times 0.25°$, but started only in 1998. 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. Temperatures comes from the Interim ECMWF Reanalysis (ERAI), described above. This alternative malaria measure is more precise, but is based on rainfall and temperature over the period 1998–2010.

To combine gridded data with our survey data, we have intersected maps of administrative district boundaries in 1981, 1991, 2001 and 2011 with the gridded malaria data, we have computed the percentage of each district area covered by each grid cell and computed area-weighted average of malaria over district units. Survey data have been matched with the relevant district level measure : district malaria measures are based on the 1981 district boundaries for DHS 1,[32] on 1991 boundaries for DHS 2, on 2001 boundaries for DLHS 2, and on 2011 boundaries for DHS 4.

[32]Except for the few states whose district codes in DHS 1 are based on 1991 census, like Assam, Delhi, Punjab and Tamil Nadu.

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.

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

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

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

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

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:

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

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,

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

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

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

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.